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A PROPOSED AVIATION ENERGY CONSERVATION PROGRAM FOR THE NATIONA--ETC(U)
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A PROPOSED AVIATION ENERGY CONSERVATION PROGRAM FOR THE NATIONAL AVIATION SYSTEM

Volume II

The Intermediate and Long Run, 1979-1990

November 1978

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
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16. Abstract

This study presents an overview of potential options for improving aviation energy efficiency. Included in the proposed program are alternatives that could be pursued by the Federal Government as well as options that could be adopted by the various segments of the aviation industry. The report is in four volumes:

- Volume I - The Short Run, 1977-1978;
- Volume II - The Intermediate and Long Run, 1979-1990;
- Volume III- The Proposed Aviation Energy Conservation Program; and
- Summary - Overview of preceding technical volumes.

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INTRODUCTION

Volume I of this study outlines a policy generation methodology and uses the methodology to analyze short run options to improve aviation energy efficiency. Intermediate and long run energy conservation policy options are evaluated in this volume. The Goal Clarification, Progress in Fuel Conservation, Analysis of Conditions, and Projection of Developments steps in the policy generation methodology need not be repeated from Volume I. Instead, Identification of Policy Options and Synthesis and Evaluation of Policy Options, the last two steps in the policy generation methodology, are all that is required for the analysis which follows.

While the division between the intermediate and long run timeframes is somewhat arbitrary, options are nevertheless classified in the period in which they have significant effect. Some energy conservation policy options (e.g., area navigation) are accordingly listed in more than one timeframe due to the lengthy implementation time for those particular options. In general, however, policy options neatly divide into procedural changes in the short run, capacity increases, and extensions of existing technology in the intermediate run, and technological advances in the long run. The short run options generated in Volume I and the intermediate and long run options generated in this volume are integrated into the proposed Aviation Energy Conservation Program in Volume III.

As stated above, this volume delineates the intermediate and long run policy options for the study. The intermediate run is defined as that timeframe long enough so that airport capacity changes can be instituted and derivative aircraft introduced, yet short enough so that new technology aircraft cannot be put into operation. The definition is, therefore, somewhat arbitrary and is primarily a classification convenience. Given the current economic environment and plans of the airline and airframe corporations, the intermediate run is defined as the calendar years 1979-1981. The long run is then defined as the period 1982-1990.

This volume is effectively partitioned into two mutually exclusive sections: Chapters 1 and 2 deal with the intermediate run energy conservation policy options and Chapters 3 and 4 analyze the long run options. In Chapter 1, the intermediate run options are identified. In Chapter 2, each option is assessed as to its effect on fuel conservation and other policy options such as safety, compatibility with other energy conservation policy options within the

same timeframe, and technical feasibility. The long run options are specified in Chapter 3 and subsequently analyzed in Chapter 4. In Chapter 5, a summary listing of the intermediate run and long run energy conservation policy options is provided. These are the options determined to be both feasible and effective within each timeframe. A tentative forecast for each set of options completes this volume. The intertemporal policy set derived in Volume III is a subset of these options plus the similarly derived short run policy option set in Volume I.

CHAPTER I

ENERGY CONSERVATION POLICY OPTIONS:

1979-1981, THE INTERMEDIATE RUN

The short run energy conservation policy options are essentially operational changes within the context of existing airport capacities and existing technology. During the intermediate run timeframe, calendar years 1979-1981, airport capacity can be increased and extensions of existing technology can lead to derivative or modified aircraft. Portions of the FAA Upgraded Third Generation Air Traffic Control System (UG3RD) will also be introduced, raising the effective capacity of airports. The intermediate run options are presented according to the following classification scheme:

A. AIR TRAFFIC CONTROL

1. Terminal, En Route, and Flow Control Automation
2. Expand Use of Area Navigation (RNAV)
3. Wake Vortex Avoidance Systems at Major Airports

B. AIRPORTS

1. Ground Movement of Aircraft Under Alternate Power Sources
2. Fog Dispersal Systems
3. Dual-Lane Runways

C. ENGINE TECHNOLOGY

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2. Retrofit with JT8D Engines
3. Retrofit with JT10D/CFM 56 Engines

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1. Derivative Aircraft
2. Lighter-Than-Air Vehicles
3. Winglets

4. Wing Tip Extensions

5. Aft Body Modifications

6. On-Board Performance Computers

Several intermediate run options which were initially considered, but deleted in the early analysis are presented in the Appendix.

1. TERMINAL, EN ROUTE, AND FLOW CONTROL AUTOMATION

The state-of-the-art in terminal automation is known as ARTS III (Automated Radar Terminal System) which is now operational in sixty-four locations. The heart of the ARTS system is a general purpose computer which processes digitized sensor data and flight plan data in a manner which makes it usable for those computations required for advanced automation functions. Basically, it is an alphanumeric tracking system which uses a digital computer. The terminal automation program involves improvements to ARTS III. Altogether, five enhancement packages are in process or under consideration. Of primary importance to fuel conservation is the planned improvements to metering and spacing (Basic in 1984, Advanced by 1990).

Present third generation air traffic control includes a semi-automated en route air traffic control component. There are 25 en route sites in the National Airspace System of which 20 are computer equipped. The major functional capabilities in the present system include: on-line entry of proposed flight plans, automatic data exchange between ATC facilities, automatic error and legality checking, automatic flight plan preparation/revision and updating, automatic tracking and radar input processing. The proposed enhancement program for the UG3RD may be considered in two phases, one phase requiring no major new subsystem with the other phase requiring new equipment. The en route control enhancements will facilitate area navigation techniques and also provide en route metering. Energy savings will result from decreased distances flown as well as decreased delay.

Improved terminal metering and spacing accuracy will permit movement from the present 18 seconds (1 sigma) accuracy for single runway inter-arrival spacings to 11 seconds (1 sigma) with basic metering and spacing (1984), then to 8 seconds (1 sigma) with advanced metering and spacing (1990).

2. EXPAND USE OF RNAV

Area navigation provides the capability for aircraft to fly routes other than straight-line segments from one navaid to another. The systems range in complexity from 2D to 4D which provide the user

aircraft with horizontal navigation data (2D), horizontal plus altitude data (3D), and the addition of scheduled time to the 3D capability (4D). The benefits of area navigation include shorter routes, improved arrival and departure procedures, more economic climb and descent profiles, and increased operations (climb/en route/descent). Full implementation of RNAV could reduce route miles flown by as much as 2 percent. 1/

The current RNAV system consists of ground-based components as well as the avionics systems that are carried within the aircraft for navigation. RNAV avionics derive the aircraft's position continuously from VORTAC, VOR, and/or DME ground stations. Future plans are for increases to these system elements plus new parallel offset routes and three-dimensional routes. With the growth of new RNAV routes, there will be a corresponding increase in ground-based facilities and equipment and software such as VORTAC sites, ARTS software, and NAS software.

At present, RNAV avionics systems are installed on only a minor portion of the aircraft fleet. The use of RNAV is voluntary and the relatively high cost of equipment has slowed acceptance. Avionics costs currently range from $2,400 to $25,000 per aircraft.

3. WAKE VORTEX AVOIDANCE SYSTEMS AT MAJOR AIRPORTS

The Wake Vortex Avoidance System (WVAS) is being developed for use in the terminal airspace to detect and/or predict the presence of aircraft wake vortices, to evaluate whether a threat exists to a following aircraft, and to command the hazard avoidance section of that aircraft. A Vortex Advisory System (VAS), precursor to the WVAS, has been installed at Chicago's O'Hare Airport and is expected to be operational during 1978. In the absence of an operational means to detect or predict the location and severity of wake vortices, the FAA has currently maintained separation standards from 3 nautical miles (nmi), which was in common use prior to the introduction of wide-bodied aircraft, to at least 5 nmi for light aircraft following heavy aircraft.

The imposition of this 5 nmi spacing during IFR conditions and the practices used by pilots during Visual Flight Rule (VFR) conditions to assure safe separation have caused roughly a 10 percent loss in runway acceptance rates under IFR and a 10-20 percent loss in the VFR rate. 2/

1/ J. E. Dratch, Airline Energy Conservation Options Summary Document, mimeographed, July 27, 1973.

2/ "An Overview and Assessment of Plans and Programs for the Development of the Upgraded Third Generation Air Traffic Control System," FAA-EM-75-5, March 1975, DOT/FAA.

4. GROUND MOVEMENT OF AIRCRAFT UNDER ALTERNATE POWER SOURCES

Airplanes consume a substantial amount of fuel while operating on the ground. The FAA funded a study to investigate alternative methods of towing aircraft. Towed airplanes would reduce airport noise and air pollution and result in substantial fuel savings.

Each of the following systems has potential as an alternate source for aircraft ground movement:

1. Powered landing gear
2. Externally powered main landing gear
3. Externally powered nose gear
4. Cable tow
5. Four-wheel articulated tractor
6. Four-wheel articulated direct-drive tractor
7. Six-wheel (4 x 2) articulated towing tractor
8. Tracked, articulated tractor

One automatic component in aircraft delay and associated fuel burn is the time and resulting fuel burn necessary to taxi from the gate to the runway before takeoff and the return leg upon landing. The only way fuel economies will be reached in this area (under existing airport designs) is to shut down the engines once an aircraft is clear of the active runway and then tow it. Considering only the 20 major hub airports in the United States, it is conservatively estimated that over one million gallons of jet fuel are consumed each day by civil air carrier jet transports taxiing or holding between terminal gates and runways. 3/ Up to 80 percent of this fuel can be saved through aircraft towing.

5. FOG DISPERSAL SYSTEMS

The objective of fog dispersal is visibility improvement; that is, provision to the pilot of the visibility needed for visual ground reference in the approach, touchdown and rollout zones of the runway. The function of the fog dispersal system complements the Instrument Landing System (ILS) function; the ILS provides a precision approach while visual ground reference is provided by the fog dispersal system.

3/ Robert W. Forsyth and John P. Forsyth, "Aircraft Ground Towing: Current Advantages and Potential Technology," Interavia, 8, 1976.

Fogs at United States airports occur on the average of only one to two percent of the time. Yet, they are responsible for substantial delay time when they occur. Fogs are generally defined as either cold fogs (temperature below $0^{o}C$) or warm fogs (temperature above $0^{o}C$). In the United States, warm fogs occur approximately 95 percent of the time while cold fogs occur 5 percent of the time when fog conditions exist. 4/ The type of fog system required is one which concentrates on warm fog dispersal.

Numerous techniques and systems have been tried based on such principles as heat, electrostatics, sound, chemical and physical additions, and mechanical mixing. Some techniques have been engineered into operational systems. Hygroscopic absorption (seeding) has been used at Seattle-Tacoma International Airport. Turboclair (jet engine generated heat) has been used at two airports in France. In Munich, Germany, the Linde AG Heat Pump System has been developed.

The existence of fog at an airport requires operations under IFR with greater separations than in VFR conditions and reduced airport capacity. Also, diversions to alternates is increased by the existence of fog. Both of these factors lead to increased fuel-consuming airborne operation.

6. DUAL-LANE RUNWAYS

Runway occupancy time affects capacity in two ways. Arrivals are affected when arrival spacing times approach runway occupancy times. This limit does not ordinarily occur today in IFR conditions because current inter-arrival times are large with respect to occupancy times. With reduced final spacings, however, runway occupancy time will have to be reduced and controlled through the provision of well located high-speed exits and possibly standard runway markings indicating speed and distance to the next exit.

Departures are affected by arrival occupancy times when arrivals and departures are mixed on the same runway. The combined time for arrival occupancy and the spacing of the succeeding arrival behind the departure places a severe restriction on how far inter-arrival times may be reduced when arrivals and departures are mixed on the same runway. Today's solution to this problem is to provide dedicated parallel runways. This solution is extremely wasteful of airport land, and the dual-lane runway has been proposed as an alternative to dedicated parallel runways.

4/ Ground Based Warm Fog Dispersal Systems - Technique Selection and Feasibility Determination With Cost Estimates, FAA-RD-75-126, November 1975.

The dual-lane runway is a very closely spaced IFR dependent runway pair (centerline spacing 700-2,499 feet). In IFR, the basic advantage is that the departure is released when the arrival crosses the threshold of the arrival runway, rather than having to wait while the arrival rolls out and exits the runway. The resulting time savings allow the inter-arrival spacings to be reduced to less than one minute without restricting departures.

The capacity benefits of dual-lane runways in mixed operations are high. A dual-lane runway provides IFR capacity gains ranging from 12 percent to 47 percent depending upon the level of control automation. 5/

7. PERFORMANCE MEASUREMENT AND EVALUATION FOR JET ENGINES

The fuel consumption performance of current engines deteriorates with use. On a fleet average basis, the rate of increase has been 0.4 to 0.6 percent per year on the older JT3D and JT8D engines and from 1 to 1.5 percent per year on the newer high-performance engines. Through a reevaluation of life cycle on engine parts, lower fuel consumption could be realized with more frequent replacement of deteriorating parts. This reevaluation would involve a computerized system to monitor the fuel performance of each aircraft, replacing deteriorated engine parts, and a revised system of planned engine overhauls to replace engine parts sooner than is currently the case. This latter approach might be implemented by expanding the workscope of planned maintenance shop visits.

8. RETROFIT WITH JT8D ENGINES

All four-engine narrow-body (ENB) and turbofan aircraft currently utilize fuel inefficient engines (JT3C for B707-120, B720, and DC-8-10; JT4A for B707-320 and DC-8-20; JT3D for B707-320 and DC-8-50/60 series). Reengining these aircraft with JT8D-209/-217 engines (refanned version) would dramatically improve the fuel efficiency of the aircraft. Furthermore, the JT8D-209 is the low noise derivative of the JT8D-9; hence, the noise footprints of the 4 ENB could be considerably improved.

9. RETROFIT WITH JT10D/CFM56 ENGINES

The new "ten ton" engines developed by United Technologies Corporation (JT10D) and GE/SNECMA (CFM56) are more fuel-efficient than any

5/ Richard M. Harris, "Future ATC Technology Improvements and the Impact on Airport Capacity," AGARD Conference Proceedings No. 188, February 1976.

existing engine. The CFM56 has a specific fuel consumption (SFC) much lower than that of the 1960's technology engines. At 5,000 lb. thrust, 0.8M, and FL300, the CFM56 has a cruise SFC of .65 versus .77 to .84 for the 1960's technology engines. The low exhaust velocities generated by these high bypass ratio engines drastically reduces the 90 effective perceived noise level (EPNL) acreage (by 99 percent for B707/DC-8's, 87 percent for 727s, and 82 percent for B737/DC-9s) for a side benefit. Retrofit could apply to the 4ENB, 3ENB, and 2ENB; however, the 4ENB retrofit is not considered likely due to airline economics.

10. DERIVATIVE AIRCRAFT

Three specific derivative aircraft options were determined as being economically viable by the RECAT study. 6/ They are:

1. Replace 25 percent of B737/DC-9 fleet with DC-9 Derivative

2. Replace aging portion of B707/DC-8 fleet (40 percent) with the DC-10 Derivative

3. Replace future DC-10 and B-747 orders with L-1011L.

The DC-9D is characterized as follows: 117 seats, 1,200 mile maximum stage, new engines (JT8D-17), winglets, general weight reduction, 171 inch stretch, leading edge extension and rerigged controls, and improved high-lift system for wings (variable camber Krueger, improved track-mounted flap, and flaperon). Flyaway price is about $7.4 million.

The DC-10D is characterized as follows: 199 seats, 2,540 mile maximum stage, new engine (CF6-50C), thick super-critical wing, general weight reduction, general drag reduction, composite secondary structure, and 360 inch shrink. Composites are used in the cabin florr beams, control surfaces, wing fixed trailing edge, wing-body fairing, flaperons, ailerons, elevators, and rudders. Flyaway price is about $15.6 million.

The L-1011L is characterized as follows: 400 seats, 2,095 mile maximum stage, a 360 inch stretch, and a flyaway price of $26.9 million.

6/ United Technologies Research Center, Cost/Benefit Tradeoffs for Reducing the Energy Consumption of Commercial Air Transportation, Report No. R76-912036-16, June 1976, pp. 94-97.

11. LIGHTER-THAN-AIR VEHICLES

Lighter-than-aircraft (LTAs), in the form of very large airships, could have significant energy benefits. Large airships can be engineered to handle cargo weighing in excess of a million pounds with improved flexibility and energy economy. Creating airships of this capacity could have an impact on air transportation due to:

1. The vertical takeoff and landing (VTOL) ability to deliver and pick up cargo without runways

2. The ability to "land by hovering" (maintaining position by thrust vector control) and winching shipments up and down

3. The inherent environmental cleanliness and quiet

4. The fact that among possible airborne vehicles, the dirigible can perhaps most practically employ nuclear propulsion in the foreseeable future

LTAs are not practical for passenger transportation due to their slow speed; hence, only all-cargo applications are considered. Existing dirigibles could be altered to function as all-cargo vehicles with a 75 ton lift capacity.

12. WINGLETS

Winglets are vertical airfoils added to each horizontal airfoil (wing) tip. The purpose of winglets is to lower drag due to lift and to disperse the wing tip vortex. Estimates for drag reduction are typically 10 percent. The increased lift/drag ratio produces fuel savings.

An analysis by the Lockheed-California Company 7/ projected a 3 percent fuel savings by the use of wing tip extensions of three to four feet and slightly less for winglets on the basis of wind tunnel data comparison.

13. WING TIP EXTENSIONS

A 3 to 4 foot extension of each wing tip raises the lift/drag ratio and disperses the wake vortex much as winglets do. Wind

7/ Cost/Benefit Tradeoffs for Reducing the Average Consumption of Commercial Air Transportation System, Lockheed-California Company, April 7, 1976 (part of RECAT study).

tunnel tests by Lockheed have suggested a slight superiority of wing tip extensions over winglets, but the effect is both airplane and speed dependent. For example, at 0.84 Mach, the L-1011 basic wing has a lift/drag ratio of 16.5. With winglets, the ratio is 18.7 and with wing tip extensions it is 19.1. However, the slight superiority disappears with lower speeds and/or the use of different aircraft.

14. AFT BODY MODIFICATIONS

Modifications to the engine aft body result in fuel savings of 3.4 percent at 0.83M and up to 8 percent at 0.87M (RECAT - Lockheed). The modifications consist of a totally redesigned engine aft body using improved materials so as to raise the engine thrust-to-weight and thrust-to-volume ratios.

The General Drag Reduction Program would vary from aircraft type to type using the B727-200 as an example, drag reduction would include control surface rigging items, seals leakage items, and surface irregularity items.

15. ON-BOARD PERFORMANCE COMPUTERS

The use of an on-board computer to optimize fuel utilization by the aircraft has been studied for the following functions: (1) fuel conservative descent profile, (2) maintain RNAV route, (3) hot start monitoring, (4) aircraft health monitoring, (5) automatic performance reserve, (6) on-time arrival assurance, and (7) processing of radar and other digital data for display to pilot.

Boeing is studying a computer which would be self-correcting; i.e., the computer would compare actual airplane performance to ideal performance and system corrections would be made automatically to remove the divergence.

CHAPTER II

SYNTHESIS AND EVALUATION OF

INTERMEDIATE RUN POLICY OPTIONS

The intermediate run policy options delineated in Chapter I of this volume are synthesized and evaluated in this chapter to form a coherent intermediate run option set for aviation energy conservation. Each option is assessed as to its effect on energy as well as non-energy factors such as aviation safety, compatibility with the other intermediate run policy options, and political and technical feasibility. The Energy Policy Evaluation Model developed in Volume I of this study is briefly reviewed below. The list of options from Chapter I are partitioned into coherent groups according to the variable in the model which each option impacts. A detailed analysis of the options by these groupings follows. Finally, the policy interactions are evaluated and a final intermediate run energy conservation policy set is developed. This policy set is used to forecast energy conservation on the assumption that it is instituted in its entirety and in isolation from the final short run and long run policy sets. The short, intermediate, and long run policy sets are processed in a final synthesis in Volume III to derive a comprehensive proposed Aviation Energy Conservation Program.

The Energy Policy Evaluation Model

The Energy Policy Evaluation Model shown in Table 1 presents the percentage change in the goal variable, Revenue Ton-Miles Per Gallon (RTM/G), in terms of eight components. A detailed discussion of the model and its components is provided in Volume I, Chapter VI of this study. The model is oriented towards evaluating the energy efficiency of the passenger/cargo certified route air carriers. For the all-cargo carriers, the first three components on the right hand side of Equation 7 should be combined into one term, RT/A, the percentage change in revenue tons per aircraft. Also, evaluating the impact of policy options on general aviation would depend solely upon the effect of such options on the right hand terms of Equation 4 of the model, since, with the exception of Air Taxi Operations, Revenue Ton-Miles are not measured for general aviation activity.

Specific Option Evaluation

The Energy Policy Evaluation Model is used to evaluate the policy options listed in Chapter I. To relate the options to the appropriate variables within the model, the following approach is used:

TABLE 1

THE POLICY EVALUATION MODEL

1. $RTM = \frac{RT}{P} \cdot \frac{P}{S} \cdot \frac{S}{A} \cdot A \cdot M$

2. $\delta RTM = \delta\frac{RT}{P} + \delta\frac{P}{S} + \delta\frac{S}{A} + \delta A + \delta M$ (See Note 1)

3. $G = \frac{G}{H} \cdot \frac{H}{M} \cdot \frac{M}{D} \cdot \frac{D}{A} \cdot A$

4. $\delta G = \delta\frac{G}{H} + \delta\frac{H}{M} + \delta\frac{M}{D} + \delta\frac{D}{A} + \delta A$ (See Note 1)

5. $\delta\frac{RTM}{G} = \delta RTM - \delta G$ (See Note 1)

6. $\delta\frac{RTM}{G} = \delta\frac{RT}{P} + \delta\frac{P}{S} + \delta\frac{S}{A} + \delta A + \delta M - \delta\frac{G}{H} - \delta\frac{H}{M} - \delta\frac{M}{D} - \delta\frac{D}{A} - \delta A$ (See Note 1)

7. $\delta\frac{RTM}{G} = \delta\frac{RT}{P} + \delta\frac{P}{S} + \delta\frac{S}{A} + \delta M - \delta\frac{G}{H} + \delta\frac{M}{H} - \delta\frac{M}{D} - \delta\frac{D}{A}$ (See Note 1)

RTM = Revenue Ton Miles
RT = Revenue Tons
P = Number of Passengers
S = Number of Passenger Seats
A = Number of Aircraft
M = Number of Miles Flown
G = Gallons of Fuel Burned
H = Number of Hours Flown
D = Number of Departures

Note 1: The above equations are not exact but are satisfactory approximations when the percentage changes are small.

Note 2: The operator "δ" represents "percentage change in."

the method of increasing RTM/G is based upon the variables of the model; the options are then listed that primarily impact the method variable. Each option is quantitatively evaluated to determine its impact on RTM/G. The method of RTM/G increase, the options for the method, and the quantitative impact analysis are presented according to the outline in Table 2.

Several of the options required an evaluation using the civil aviation fleet mix. Since the relevant timeframe for the Intermediate Run analysis is 1979-1981, the 1980 Baseline Air Carrier Fleet shown in Table 3 was used for that evaluation. The 1980 baseline fleet assumes no option implementation; that is, no derivative, modified, or new aircraft. It is likely that the 1980 fleet will differ from that of Table 3 because it is likely that some of the energy conservation options will, in fact, be implemented.

1. METHOD: REDUCE GALLONS PER HOUR BY REDUCING DELAY

OPTIONS:
- o Dual-Lane Runways
- o Fog Dispersal Systems
- o Terminal, En Route, and Flow Control Automation
- o Wake Vortex Avoidance Systems at Major Airports

The dual-lane runway is a very closely spaced IFR dependent runway pair. The basic advantage is that the departure is released when the arrival crosses the threshold rather than after the arrival exits the runway. IFR capacity gains range from 12 to 47 percent. Conversion of 10 percent of delay-related runways to dual-lane would conserve .1 percent of fuel consumption. (a)

Note (a): A one percent increase in capacity reduces delay by 2.0 to 2.5 percent (discussions with FAA). A 2 percent reduction in delay would lower fuel consumption by .14 percent (roughly 7 percent of annual aviation fuel is consumed in delay and 2 percent of 7 percent = .14 percent). For purposes of convenience, the relationship is reduced to a one percent increase in capacity equals a .1 percent decrease in fuel consumption and, in turn, a .1 percent increase in RTM/G. This capacity - consumption relationships is used extensively in delay analysis.

For dual-lane runways, capacity gains of 12 percent (IFR minimum capacity increase) convert to fuel savings of 1.2 percent per runway conversion. Conversion of 10 percent of delay-related runways would conserve .1 percent of annual aviation fuel consumed.

TABLE 2

INTERMEDIATE RUN POLICY OPTION GROUPINGS

REDUCE GALLONS PER HOUR BY REDUCING DELAY

- o Terminal, En Route, and Flow Control Automation
- o Wake Vortex Avoidance Systems at Major Airports
- o Fog Dispersal Systems
- o Dual-Lane Runways

REDUCE GALLONS PER MILE BY USING IMPROVED ENGINE TECHNOLOGY

- o Retrofit With JT8D Engines
- o Retrofit With JT10D/CFM56 Engines

REDUCE GALLONS PER HOUR AND HOURS PER MILE (Gallons Per Mile) BY USING IMPROVED AIRCRAFT TECHNOLOGY

- o Winglets
- o Wing Tip Extensions
- o Aft Body Modifications
- o Lighter-Than-Air Vehicles
- o Derivative Aircraft

REDUCE GALLONS PER MILE BY USING IMPROVED OPERATIONAL SYSTEMS

- o Performance Measurement and Evaluation for Jet Engines
- o On-Board Performance Computers

REDUCE GALLONS PER HOUR BY IMPROVING GROUND OPERATIONS

- o Ground Movement of Aircraft Under Alternative Power Sources

REDUCE ACTUAL MILES FLOWN

- o Expand Use of Area Navigation (RNAV)

TABLE 3

1980 BASELINE AIR CARRIER FLEET

(Assumes No Derivative, Modified, or New Aircraft)

TWO-ENGINE TURBOJET		720
B737/DC-9	700	
BAC-111	20	
THREE-ENGINE TURBOJET		1,234
B727	1,024	
DC-10	125	
L-1011	85	
FOUR-ENGINE TURBOJET		615
B707/DC-8	515	
B747	100	
TURBOPROP		263
PISTON		60
ROTARY-WING		15
TOTAL BASELINE FLEET		2,907

Fog dispersal systems improve visibility. Their primary use would be to transform CAT III conditions to CAT II, occasionally to CAT I, over the airport runways. Warm fogs are the primary problem. Heat-based systems appear most promising. A one percent increase in system capacity by use of fog dispersal systems would conserve .1 percent of annual fuel consumption (fogs occur one to two percent of the time at United States airports). A tradeoff exists to the extent that fog dispersal systems consume energy in operation.

Control automation throughout the ATC system will increase capacity, reduce delay, and assist in transferring airborne delay to the ground. A primary gain will be improved metering and spacing accuracy which would permit reduced separations and corresponding capacity gains. Up to 2.5 percent of annual aviation fuel could thus be conserved. (b)

The purpose of a Wake Vortex Avoidance System (WVAS) is to detect or predict wake vortices, to evaluate threats to aircraft, and to command the hazard avoidance section. Aircraft spacing can be reduced once wake vortices can be accurately evaluated producing a 10 percent nominal increase in capacity and a 1 percent increase in RTM/G. In the short run, .21 percent of the gain is expected, the balance in the intermediate term.

The gains from Control Automation and from Wake Vortex Avoidance Systems are not additive. Both involve fuel conservation through reduced aircraft separations. The 2.5 percent gain through Control Automation includes the 1 percent gain from WVAS. Therefore, the gains through Control Automation over the gain from WVAS equals 1.5 percent. Further, the gain from Control Automation includes at least half the short run gain reported from FAD adoption of 1.7 percent. On an incremental basis, Control Automation adds .6 to RTM/G over the gains from WVAS and the short term gains from FAD.

Note (b): If the 10 second gain in accuracy from advanced metering and spacing (18 seconds to 8 seconds) results in a 10 second reduction in time between operations, then operations per hour on two intersecting runways could increase from a typical 74 to 92 for a 25 percent gain in capacity. Single runway percentage gains would be smaller and parallel runways gains greater. Using a ten-to-one ratio of capacity gains to fuel reduction, the resulting fuel savings and increase in RTM/G would be 2 percent.

TIME FRAME: DELAY REDUCING OPTIONS

Cumulative Impact on RTM/G	1979	1980	1981
Option			
Dual-Lane Runways	0.02%	0.08%	0.10%
Fog Dispersal System	0.02%	0.08%	0.10%
Control Automation	0.12%	0.50%	0.60%
WVAS	0.16%	0.65%	0.80%

2. METHOD: REDUCE GALLONS PER MILE BY USING IMPROVED ENGINE TECHNOLOGY

OPTIONS: o Retrofit with JT8D Engines

o Retrofit with JT10D/CFM56 Engines

The baseline aircraft fuel efficiencies of Table 4 show the B707/DC-8 at 2.079 RTM/G, the B727 at 2.082 RTM/G, and the B737/DC-9 at 2.117 RTM/G. The 1975 value of 2.210 was achieved, therefore, in spite of the dominant aircraft in the fleet. The B747 has a fuel efficiency of 2.982 RTM/G, while the value for the DC-10/L-1011 is 2.716. If the engines on the narrow-bodied aircraft were replaced with more fuel efficient, high-bypass-ratio engines, the existing fleet could show considerable increases in fuel efficiency.

The B707/DC-8 fleet is using aging JT3C, JT3D, and JT4A engines. The reengining of 4ENB turbojet and turbofan aircraft is best accomplished with the refanned version of the JT8D-209. This option was evaluated in the RECAT [8] study which estimated a 23 percent fuel savings for the DC-8-20/30 and a 10 percent savings for all B707, B720, and the other DC-8 types. The cost of the modifications was estimated at $4.5 million for the DC-8-20/30 and $4.72 million for the remaining aircraft types.

The 1980 fleet is assumed devoid of DC-8-20/30s. Since 17.47 percent of the RTMs are attributable to 4ENB aircraft, the 10 percent

8/ RECAT Study, Douglas Aircraft Company, Final Briefing, April 7-8, 1976 (pp. PR6-GEN-21561).

fuel savings produces a fleet savings of 1.75 percent. This assumes that all 515 aircraft are reengined. At $4.72 million per aircraft, the capital investment required would be $2,431 million. Since this sum would purchase a large number of new aircraft, the retrofit decision would not likely be voluntarily taken by the air carriers. The reduction in noise levels (75 percent reduction in 90 EPNdB area) and emission levels would, of course, be positive considerations in the retrofit decision. It is assumed that a retrofit program would delay 4ENB retirements by extending the depreciation schedules by five years.

The JT10D/CFM56 engine retrofit program could be conducted for B727s and the B737/DC-9 fleet. The retrofit program would raise B727 fuel efficiency by 10 percent and B737/DC-9 fuel efficiency by 8 percent. Since the 1980 baseline RTM forecast has B727s flying 40.39 percent and B737/DC-9s 11.54 percent, the retrofit results in an overall RTM/G improvement of 4.04 percent for the B727 retrofit and 0.92 percent for the B737/DC-9 retrofit. The retrofit program would result in the reengined aircraft meeting FAR-36 XYZ standards. The depreciation schedule for retrofitted aircraft would be lengthened by five years.

It should be noted that the engine retrofit options, derivative aircraft, and the purchase of new aircraft (long run option) are all substitutes. If the retrofit programs are initiated, the other two options are not feasible and so on. Under the assumption that the options are utilized, however, the timeframe for the effects is shown below. A three year retrofit program is assumed for all aircraft with equal numbers of aircraft retrofitted each year.

TIME FRAME: ENGINE RETROFIT OPTIONS

Cumulative Impact on RTM/G	1979	1980	1981
Option			
Retrofit DC-8/B707 with JT8D	0.58%	1.16%	1.75%
Retrofit DC-9/B737 with JT10D/CFM56	0.31%	0.62%	0.92%
Retrofit B727s with JT10D/CFM56	0.35%	2.70%	4.04%

3. METHOD: REDUCE GALLONS PER MILE BY USING IMPROVED AIRCRAFT TECHNOLOGY

OPTIONS:
- o Winglets
- o Wing Tip Extensions
- o Aft Body Modifications
- o Lighter-Than-Air Vehicles
- o Derivative Aircraft

The above technological options can be classified as retrofit, modification, or derivation of or substitution for the existing air carrier fleet. Retrofit refers to changes to airplanes already in service; whereas, a modification program would apply to changes of future deliveries of in-production airplanes. Derivative aircraft are based upon in-production aircraft, but are sufficiently different in size or operational characteristics to warrant consideration as more than a modification program. Substitution applies to replacing conventional aircraft with LTAs.

To appreciate the impact of these technological options on RTM/G, an evaluation of the current air carrier fleet fuel consumption characteristics is needed. Table 4 gives the aircraft fuel consumption rates for the 1980 baseline fleet.

The overall fuel savings will depend upon the impact of each option upon each aircraft type and upon the relative proportion of Revenue Ton-Miles accounted for by that particular aircraft type. Overall activity levels need not be considered, since an efficiency measure, RTM/G, is being used to evaluate each option. If an absolute value measure, like total gallonage consumed, were used, then reduction in air travel resulting from air fare increases to defray the cost of the energy options would have to be considered.

Table 5 provides the proportion of 1980 Seat-Miles and Revenue Ton-Miles accounted for by each aircraft category. The proportions were determined by obtaining 1975 proportions on a per aircraft basis by type from the CAB Aircraft Operating Cost and Performance Report. The proportions were then applied to the fleet composition as detailed in Table 3. Differential impacts can be expected by aircraft type especially wide-body versus narrow-body, so overall fuel impacts by options can be evaluated by the weightings of Table 5. The proportions of available cargo space per passenger, RT/P in the Model, accounts for the slight variations in the two columns of Table 5.

TABLE 4

1980 BASELINE FUEL EFFICIENCY

Aircraft Type	Number in Fleet	Gallons Per Mile	Average Seats	Gallons Per Seat Mile	Average Revenue Tons	RTM/G
B747	100	7.413	350	0.0212	22.1	2.98
DC10/L-1011	210	5.560	250	0.0222	15.1	2.72
B707/DC-8	515	4.280	145	0.0295	8.9	2.08
B727	1024	3.458	120	0.0288	7.2	2.08
B737/DC-9	720	2.928	95	0.0308	6.2	2.12
Turboprop	263	1.296	50	0.0259	3.6	2.78
Piston	60	1.180	40	0.0295	3.2	2.71
Rotary-Wing	15	1.514	25	0.0606	1.1	0.73

Source: FAA/AVP Bulletin AVP-76-2 and CAB Aircraft Operating Cost and Performance Report (July 1975).

TABLE 5

PROPORTION OF AVIATION ACTIVITY MEASURES

BY AIRCRAFT TYPE, 1980

Aircraft Type	Percent Seat Miles	Percent RTMs
B747	12.36	13.03
DC-10/L-1011	15.66	15.80
*B707/DC-8	17.05	17.47
B727	40.32	40.39
B737/DC-9	13.38	11.54
Turboprop	1.20	1.74
Piston	0.02	0.02
Rotary	0.01	0.01
TOTAL	100.00	100.00

*Note: RTM proportions of 4.59 percent for DC-8-62/B707-300 and 12.88 percent for other DC-8/B707 (No DC-8-20/30).

The Reducing the Energy Consumption of Commercial Air Transportation (RECAT) study by United Technologies Research Center serves as the basis for much of the analysis herein. In Report No. R76-912036-16 of that study (Cost/Benefit Tradeoffs for Reducing the Energy Consumption of Commercial Air Transportation, June 1976) several of the above options were studied. One difference between the options above and those of RECAT is that in RECAT winglets or wingtip extensions and a general drag reduction program were combined into an option called the aerodynamic retro/mod package. The analysis below evaluates each option separately. The analysis is basically divided into two parts: (1) Retro/Mod, and (2) Derivative/Substitute. Winglets, Wingtip Extensions, and Aft Body Modifications are evaluated in the former and Derivative Aircraft and LTA Vehicles in the latter.

1. RETROFIT/MODIFICATION (R/M) OF EXISTING AIRCRAFT

The RECAT study combined the three Retro/Mod options into one as stated above. The effort of the R/M program is summarized by aircraft type in Table 5 where the effect of the program on operating cost and the cost of the capital improvements are included. By weighting the fuel savings of Table 6 by the proportion of RTMs accounted for by aircraft type in Table 5, the fuel savings for the 1980 baseline fleet is calculated as 4.98 percent.

The Retro/Mod schedule is presented in Table 7 and is utilized later to timeframe the fuel impacts.

The breakout of the overall fuel impact is taken to be 3 percent for both wingtip extensions and winglets and the residual for aft body modifications. An analysis by the Lockheed-California Company (NAS2-8612,7, April 1976) projected a 3 percent fuel savings by the use of wingtip extensions of three to four feet and slightly less for winglets on the basis of wind tunnel data comparison. The differences were slight and likely to be airplane-specific, however, so a 3 percent savings is assumed for each type of wing modification. The same study projected a 3.4 percent fuel savings for aft body modification. That estimated savings is apparently a fleet weighted average; hence, the difference between the total fuel savings for each aircraft in Table 6 and 3 percent is taken to be the fuel savings due to the aft body modification program. The weighted results are consistent with the Lockheed program. If the Retro/Mod program is applied, the aging fleet of DC-8/20/30/50s

TABLE 6

EFFECT OF AERODYNAMIC RETRO/MOD PROGRAM

BY AIRCRAFT TYPE

Aircraft	Fuel Saving (Percent)	Operating Cost ($/Block Hr.)	Capital Cost ($K)
B747	7.5	5	250
DC-10/L-1011	7.5	6	250
B727/DC-9/B737	4.0	1	80
DC-8-20/30	5.0	3	150
DC-8-50/B707-100/B720	5.0	4	150
DC-8-61	5.0	4	150
DC-8-62/B707-300	2.0	6	150

Source: United Technologies Research Center, Cost/Benefit Tradeoffs for Reducing the Energy Consumption of Commercial Air Transportation, NASA CR-137877, Report No. R76-912036-16, June 1976, Table XV.

TABLE 7

RETRO/MOD PROGRAM SCHEDULE ON CUMULATIVE PERCENTAGE BASIS

Modification Year	DC-9 B737	B727	B707-100-20 DC-8-20/51/52	B707-300 DC-8-61/62	L-1011 DC-10	B747
1	55%	22%	43%	44%	45%	95%
2	100%	44%	86%	88%	90%	100%
3		66%	100%	100%	100%	
4		88%				
5		100%				

Source: Coykendall, R. E., et. al., Study of Cost/Benefit Tradeoffs for Reducing the Energy Consumption of the Commercial Air Transportation System, NASA CR-137891, June 1976, Table 5-1.

and B707-100s may or may not be included. The effect on the total RTM/G impact of excluding the aging fleet for implementation of all Retro/Mod programs would be to decrease the impact from 4.98 percent and 4.34 percent.

2. DERIVATIVE/SUBSTITUTE OPTIONS

The purchase of derivative aircraft or LTAs in the intermediate run timeframe depends upon airline finances and the relative profit superiority of such aircraft over the existing fleet. Only the latter consideration is examined since the availability of capital to the airline industry is outside the scope of this study. The derivative aircraft considered are those of the RECAT study, specifically: a DC-9 derivative (DC-9D), a DC-10 derivative (DC-10D), and a stretched version of the L-1011 (L-1011L). The lack of Boeing derivatives may reflect the value judgments of the RECAT study participants and the DC-9D may be considered as a generic type and consistent with a derivative of the B737. The pertinent characteristics of the derivative aircraft are provided in Table 8 (LTA aircraft characteristics are also included). The superiority of the L-1011L to all existing aircraft with respect to Seat Miles Per Gallon or RTMs Per Gallon is quite marked and is discussed in great detail in the RECAT documents. 9/ The values in Table 8 are the results of calculations based upon data and assumptions from various RECAT documents and may not coincide exactly with proprietary RECAT information. The derivative options are evaluated as follows: (1) DC-9D replaces 25 percent of B737/DC-9 only, (2) DC-10D replaces 40 percent of the B707/DC-8 fleet, and (3) L-1011L is purchased instead of DC-10 and B747 during the analysis period. These cases correspond approximately to those analyzed in the RECAT study. By utilizing Tables 5 and 8, the impact on RTM/G by case is calculated with respect to the 1980 fleet as: (1) 0.38 percent, (2) 3.43 percent, and (3) 0.66 percent. Note that the 1980 baseline fleet has a RTM/G total of 2.3676. The L-1011L replaces only 6 B747s for the intermediate run timeframe, accounting for a small impact in this timeframe. The fact that the impact is as high as 0.66 percent, however, is an indication of the assumed fuel efficiency superiority of the L-1011L relative to B747.

The LTA aircraft is assumed to serve only as an all-cargo transport. The substitution of LTAs for all-cargo aircraft will be quite limited in the intermediate run. In CY-1975,

9/ United Research Technologies Center, Cost/Benefit Tradeoffs for Reducing the Energy Consumption of Commercial Air Transportation, Report No. R76-912036-16, June 1976, pp. 94-97.

TABLE 8

FUEL CONSUMPTION CHARACTERISTICS

OF DERIVATIVE AND LTA AIRCRAFT

Aircraft	Gallons Per Mile	Average Seats	Seat Miles Per Gallon	Average Revenue Tons	RTM/G
DC-9D	2.883	117	40.58	7.0	2.43
DC-10D	4.307	199	46.20	14.3	3.32
L-1011L	6.880	400	58.14	24.0	3.49
LTAF	4.000	--	--	45.0	11.25

Sources: (1) DC-9D and DC-10D; McDonell-Douglas RECAT Study Final Briefing, April 7-8, 1976.

(2) L-1011L; Lockheed-California Company Report No. LR-27637, April 7, 1976, and United Technologies Research Center Report No. R76-912036-16.

(3) Lighter-Than-Air Freighter (LTAF).

the domestic all-cargo airlines had an average capacity of 53.4 tons per aircraft and flew a total of 464 million RTMs.

Since total domestic RTMs for 1975 were 15,921.9 million, only 2.9 percent of domestic RTMs are accounted for by all-cargo operations (data from ATA, Air Transport 1976). Further, the all-cargo airlines utilized about 260 million gallons of jet fuel; hence, RTM/G was 1.785 for the all-cargo carriers. From Table 8, the fuel efficiency of the Lighter-Than-Air Freighter (LTAF) is estimated to produce a RTM/G value of 11.25. The replacement of 10 percent of the all-cargo tonnage capacity by LTAs could raise the all-cargo RTM/G to 2.7315. Since the 1980 baseline value was previously estimated at 2.37, RTM/G could be raised by 1.14 percent to 2.397 for a 10 percent all-cargo replacement. The effect is linear, so a 5 percent replacement would raise RTM/G by 0.57 percent, a one percent replacement rate by 0.11 percent, and so on. A 5 percent replacement rate is possible by 1981, hence, the maximum intermediate run impact is 0.57 percent.

The impacts of options 1, 2, and 3 are allocated over times based on Table 7 with the exception that the fourth and fifth year modifications on B727s are assumed capable of realization in the third year. The impacts of options 4 and 5 are allocated by application of S-curve techniques. 10/ The options are assumed to impact first in 1979 and reach full potential by the end of 1981.

10/ Substitution curves (S-curves) are mathematical functions representing the rate at which new technology will replace existing technology. A discussion of the technique and the function used herein for substitution is contained in James R. Bright, Technology Forecasting, The Pemaquid Press, pp. 6-41 to 6-51.

TIME FRAME: AIRCRAFT TECHNOLOGY OPTIONS

Cumulative Impact on RTM/G	1979	1980	1981
Option			
1. Winglets	1.27%	2.15%	3.00%
2. Wingtip Extensions	1.27%	2.15%	3.00%
3. Aft Body Modifications			
a. All Aircraft	2.10%	3.56%	4.98%
b. Exclude B707/DC-8	1.83%	3.11%	4.34%
4. Derivatives			
a. DC-9D	0.06%	0.31%	0.38%
b. DC-10D	0.62%	2.86%	3.43%
c. L-1011L	0.11%	0.54%	0.66%
5. LTA	0.10%	0.47%	0.57%

4. METHOD: REDUCE GALLONS PER MILE BY USING IMPROVED OPERATIONAL SYSTEMS

OPTIONS:

- Performance Measurement and Evaluation for Jet Engine
- On-Board Performance Computers

The Performance Measurement and Evaluation Program (PMEP) is oriented strictly towards the replacement of engine parts as such parts deteriorate. The savings would be approximately .5 percent on narrow-body aircraft and 1.2 percent on wide-bodies versus the current part replacement procedures. Given the baseline 1980 fleet RTM proportions as listed in Table 9, the PMEP would increase RTM/G by 0.70 percent (.5 percent * .7117 + 1.2 percent * .2883).

The On-Board Performance Computer (OBPC) is less aircraft specific. To the extent that the OBPC does aircraft health monitoring, it serves as a substitute for the PMEP. The effect of hot start

TABLE 9

1980 BASELINE FUEL EFFICIENCY

Aircraft Type	Number in Fleet	Gallons Per Mile	Average Seats	Seat Miles Per Gallon	Average Revenue Tons	RTM/G
B747	100	7.413	350	47.21	22.1	2.98
DC10/L-1011	210	5.560	250	44.96	15.1	2.72
B707/DC-8	515	4.280	145	33.88	8.9	2.08
B727	1024	3.458	120	34.70	7.2	2.08
B737/DC-9	720	2.928	95	32.45	6.2	2.12
Turboprop	263	1.296	50	38.58	3.6	2.78
Piston	60	1.180	40	33.90	3.2	2.71
Rotary-Wing	15	1.514	25	16.51	1.1	0.73

Source: FAA/AVP Bulletin AVP-76-2 and CAB Aircraft Operating Cost and Performance Report (July 1975).

monitoring and other functional calculations would result in a 0.8 percent increase in RTM/G. Thus, the total impact, including the PMEP function, is a 1.5 percent increase in RTM/G.

Both options could be implemented within the three year span and a three year S-curve (.1667, .818, 1.0) is utilized to timeframe the impacts.

TIME FRAME: IMPROVED OPERATIONAL SYSTEMS OPTIONS

Cumulative Impact on RTM/G	1979	1980	1981
Option			
PMEP	0.12%	0.57%	0.7%
OBPC	0.25%	1.23%	1.5%

Note: The options are substitutes. The OBPC impact if PMEP is also implemented is the difference between the option impacts.

5. METHOD: REDUCE GALLONS PER HOUR BY IMPROVING GROUND OPERATIONS

OPTION: o Ground Movement of Aircraft Under Alternate Power Sources

Airplanes consume a substantial amount of fuel while on the ground. The towing of airplanes between gate and runway would save approximately 80 percent of the one million gallons of fuel per day consumed in taxiing or holding. Maximum potential fuel savings is 3.7 percent of aviation fuel. Part of the savings from towing is not additive with other options discussed in this report. The gains from Terminal Control and WVAS will reduce ground, as well as air, delay and address the same delay as towing. Assuming half of the gains from these options is ground-oriented, then one percentage point of the gain from towing is nonadditive, leaving a net effect of 2.7 percent. This net effect is utilized in the cross-impact analysis of Volume IV. Here the gross effect is reported.

The timeframe for the option impact is assumed to follow a three year S-curve.

TIME FRAME: TOW AIRCRAFT OPTION

Cumulative Impact on RTM/G	1979	1980	1981
Option			
Tow Aircraft	.62%	3.03%	3.70%

6. METHOD: REDUCE ACTUAL MILES FLOWN

OPTION: o Expand Use of Area Navigation (RNAV)

Area navigation provides the capability for aircraft to fly routes other than straight-line segments from one navaid to another. At present, approximately 170 routes and 300 approach procedures have been incorporated in the RNAV system. Future plans are for increases to these system elements plus new parallel offset routes and three-dimensional routes. Full implementation of RNAV could reduce route miles flown by as much as an additional 2 percent over the present system.

The impact of RNAV was begun in the short run. The first impact is observed in 1978 with the full 2 percent not being realized until the fourth year. An S-curve is used to spread the impact. The short run (1978) effect of 20 percent has already been deducted in the timeframe below.

TIME FRAME: RNAV

Cumulative Impact on RTM/G	1979	1980	1981
Option			
RNAV	.80%	1.61%	1.80%

POTENTIAL PROGRAMS

The options and programs discussed in this report are selected so as to produce a favorable impact on energy consumption in aviation. An in-depth examination of intermediate term (1979-1981) options to accomplish energy conservation was conducted above and the impacts reported. Prior to finalization of a program based upon these options, it is necessary

to examine possible deleterious effects that implementation of these options might have on other goals of the FAA, specifically safety and the environment (noise, emissions). If an option would have a substantial negative impact on safety, noise or emissions, it should be critical to the overall objective of energy conservation before adoption.

The estimated impacts on safety, noise, and emissions of the options presented above in this chapter are summarized in Table 10. Most of the options have not only favorable impacts on energy but also have favorable impacts upon one or more additional objectives of FAA. The most obvious exception is the Dual-Lane Runways option which will negatively impact safety due to greatly reduced parallel separations of adjoining active runways. This option is not critical to the achieving of energy conservation (impact equals .1 percent by 1981, a very small savings relative to alternative options). Therefore, it is deleted from the recommended list at this stage and is not a part of further analysis.

After deletion of Dual-Lane Runways, a total of 14 options remain as viable in the intermediate timeframe. These options appear in Table 11 with their forecast impact on RTM/G by year from 1979 to 1981. Included in the listing are several options with significant interactions. Therefore, the reported impacts cannot be treated as additive.

One significant interdependency is that between the retrofit options and derivative aircraft. The noise objective of FAR 36 can be met by either retrofit or new derivatives and may even be met by a combination of the two. The impact on energy consumption by 1981 could be nearly 4 percent as a result of meeting FAR 36 noise standards with a combination of the two approaches.

A second major interdependency is that between winglets and wingtip extensions. They are almost perfect substitutes. Both options conserve fuel and also assist, to a degree, in wake vortex abatement. For a specific aircraft, one of the options would be beneficial but not both. The effect of either winglets or wingtip extensions should approach 3.0 percent by 1981, not 6.00 (3.00 plus 3.00).

These and other interdependencies are examined in greater detail in Volume III of this report where cross-impact analysis techniques are used to derive a comprehensive Aviation Energy Conservation Program.

TABLE 10

INTERACTION OF INTERMEDIATE RUN ENERGY OPTIONS WITH OTHER POLICIES

Programs	Safety	Noise	Emissions
A. AIR TRAFFIC CONTROL			
1. Control Automation	+	0	0
2. Area Navigation	0	0	0
3. Wake Vortex Avoidance Systems	+	0	0
B. AIRPORTS			
1. Ground Movement of Aircraft Under Alternate Power Sources	0	+	+
2. Fog Dispersal Systems	+	0	0
3. Dual-Lane Runways	-	0	0
C. ENGINE TECHNOLOGY			
1. Performance Measurement and Evaluation	+	0	+
2. Retrofit With JT8D Engines	0	+	+
3. Retrofit With JT10D/CFM 56 Engines	0	+	+
D. AIRCRAFT TECHNOLOGY			
1. Derivative Aircraft	+	+	+
2. Lighter-Than-Air Vehicles	0	+	+
3. Winglets	+	0	0
4. Wing Tip Extensions	+	0	0
5. Aft Body Modifications	0	0	+
6. On-Board Performance Computers	+	0	+

+ = Beneficial Effect
- = Potential Deleterious Effect
0 = Neutral Net Effect

TABLE 11

INTERMEDIATE RUN ENERGY CONSERVATION OPTION SET: MAXIMUM CUMULATIVE IMPACT ON RTM/G

	1979	1980	1981
A. AIR TRAFFIC CONTROL			
1. Control Automation	.12%	.50%	.60%
2. Area Navigation	.80	1.61	1.80
3. Wake Vortex Avoidance Systems	.16	.65	.80
B. AIRPORTS			
1. Ground Movement of Aircraft Under Alternate Power Sources	.62	3.03	3.70
2. Fog Dispersal Systems	.02	.08	.10
C. ENGINE TECHNOLOGY			
1. Performance Measurement and Evaluation	.12	.57	.70
2. Retrofit With JT8D Engines	.58	1.16	1.75
3. Retrofit With JT10D/CFM 56 Engines	1.66	3.32	4.96
D. AIRCRAFT TECHNOLOGY			
1. Derivative Aircraft	.79	3.71	4.47
2. Lighter-Than-Air Vehicles	.10	.47	.57
3. Winglets	1.27	2.15	3.00
4. Wing Tip Extensions	1.27	2.15	3.00
5. Aft Body Modifications	2.10	3.56	4.98
6. On-Board Performance Computers	.25	1.23	1.50
TOTAL	9.86%	24.19%	31.93%

Note: These options are not independent. The total, therefore, considerably overstates the achievable result from 1979-1981 and is provided as an upper bound only. This problem is addressed in Volume III of this report.

CHAPTER III

ENERGY CONSERVATION POLICY OPTIONS:

1982-1990, THE LONG RUN

The short run energy conservation policy options dealt with operational changes within the context of the existing airport capacity and existing technology. The intermediate run options dealt with capacity expanding options and extensions of the existing technology. The long run options list is dominated by technological advances in both aircraft and the ATC system. The elements of the FAA Upgraded Third Generation Air Traffic Control (UG3RD) System and Aircraft/Engine Technology constitute the bulk of the long run options. The thirteen long run options are presented according to the following classification scheme:

A. AIR TRAFFIC CONTROL

1. Direct Address Beacon System (DABS)/Automatic Traffic Advisory and Resolution System (ATARS)
2. Microwave Landing System (MLS)
3. Post-UG3RD Air Traffic Control System

B. AIRPORTS

1. STOL-Ports and STOL-Strips
2. Airport Surface Traffic Control (ASTC)

C. ENGINE TECHNOLOGY

1. Advanced Jet Engines
2. Digital Electronic Propulsion Control

D. AIRCRAFT TECHNOLOGY

1. Active Controls
2. Composite Materials
3. Supercritical Airfoils

4. Replace Aircraft with New Near Term Aircraft

5. STOL Aircraft

6. Large Air Cargo Transports

For use in the analysis of long run options, the estimated 1990 air carrier fleet assumes no derivative, modified or new aircraft (Table 12).

1. DISCRETE ADDRESS BEACON SYSTEM (DABS) AND TRAFFIC ADVISORY AND RESOLUTION SYSTEM (ATARS)

The DABS is a cooperative surveillance system with an integral data link capability which is capable of supporting the Automatic Traffic Advisory Resolution System (ATARS). It is an evolutionary replacement for the Air Traffic Control Radar Beacon System (ATCRBS).

The fundamental difference between DABS and ATCRBS is in the manner of addressing aircraft and selecting aircraft to respond to an interrogator. In ATCRBS, all aircraft within antenna beam width are addressed with the same code where the directive of the beam will make special selection possible. However, all aircraft within the antenna beam will reply, while only those outside will not. As the antenna beam sweeps by, two aircraft in close proximity ($\pm$ 1.6 nmi) to the same antenna beam, coincident or overlapped replies known as synchronous garble will occur. In DABS, synchronous garble will not occur because each aircraft is assigned a unique address code, and each aircraft responds only to an interrogation that includes that address. Therefore, each DABS interrogation is directed at a particular aircraft. An integral part of DABS is a data link where messages may be added immediately following the discrete address, thus providing a ground-air-ground digital communications capacity.

Two major advantages accrue from the use of discrete addresses. An interrogator will be able to limit its interrogations to particular targets of interest, rather than continuously interrogate all targets within line-of-sight. Second, by appropriate timing of interrogations and channel management, aircraft responses will not overlap. As a result, two fundamental ATCRBS limitations will be overcome: system saturation, and synchronous garble.

2. MICROWAVE LANDING SYSTEM (MLS)

The Instrument Landing System (ILS), presently being used as the standard for aircraft landing guidance systems, was adopted in 1949. A fully equipped ground station consists of a localizer

TABLE 12

1990 BASELINE AIR CARRIER FLEET

(ASSUMES NO DERIVATIVE, MODIFIED, OR NEW AIRCRAFT)

TWO-ENGINE TURBOJET		
B737/DC-9/BAC-111		274
THREE-ENGINE TURBOJET		2,009
B727	1,238	
DC-10	420	
L-1011	351	
FOUR-ENGINE TURBOJET		467
B707/DC-8	220	
B747	247	
TURBOPROP/ROTARY-WING		304
TOTAL BASELINE FLEET		3,054

Note: The 1990 fleet is derived from the RECAT forecast over a 600 city-pair sample.* The percentage composition of 2, 3, and 4 engine aircraft is taken from that forecast. The total baseline fleet is assumed to grow at .5 percent compounded annually from 1980 to 1990. This is under the severe constraint of no derivative, modified, or new aircraft types. By aircraft type, the following growth rates are assumed: B727 = -9.2, B727 = +2.2, DC-10 = +12.9, L-1011 = +15.2, B707 = -8.2, and B747 = +9.5.

*United Technologies Research Center, Cost/Benefit Tradeoffs for Reducing the Energy Consumption of Commercial Air Transportation, Report No. 76-912036-17, June 1976, pp. 31.

element, a glide-slope element, and independent marker beacon. Such ILS facilities are currently installed at about 460 locations in the United States. By the end of FY-1977, new facilities raised the total to 650 systems. The ILS has inherent limitations that restrict its use in fulfilling both present and future approach and landing requirements. One problem is the susceptibility of VHF and UHF signals to interference from reflecting objects found in the vicinity of the airport (safety factor). Another characteristic limiting the operational utilization of the ILS is that it provides only a single approach path. This characteristic is not consistent with today's need to change glide-paths according to the capabilities of the specific aircraft (fuel factor) and to follow approach paths which minimize noise impact on a community (noise factor).

The proposed MLS is an air-derived system which embodies three major categories of measurement guidance: (1) angle guidance using the Time Reference Scanning Beam (TRSB) techniques of C-band, (2) flare guidance by radar altimeter or alternatively by TRSB technique, and (3) range measurement using compatible L-band Distance Measuring Equipment (DME).

The primary MLS fuel efficiency effect will be a result of different glide-paths for different aircraft, thus lowering fuel burned in approach and landing. The optimum descent profile is partially system-dependent upon MLS techniques.

3. POST-UG3RD AIR TRAFFIC CONTROL

Present air traffic control procedures (third generation) are inadequate to handle the anticipated loads of the 1980's and 1990's. For the decade of the 1980's, system improvements are underway which will lead to an upgraded Third Generation System (DABS, ATARS, MLS, RNAV, Control Automation). The needs of the 1990's are expected to be met by a Post-UG3RD, or Fourth Generation System.

This system might be characterized by the following features:

1. Use of satellites over the conterminous United States (CONUS) and contigous oceanic regions (AEROSAT in the Atlantic plus others) as a primary mechanization for universal coverage surveillance, navigation, and data link communication, in conjunction with aircraft avionics integrated at the functional level (CONUS and AEROSAT may coexist with the military GPS satellite system).

2. Continuation of the current philosophy of ground-based air traffic management by Tactical Control, augmented by Strategic Control, a technique emphasizing extensive pre-planned, time-scheduled conflict-free flights, especially in regions of high air traffic density.

3. Centralization of the control and data processing networks into two or three en route control facilities.

4. A high degree of automation to constrain the growth in operational cost.

The current Post-UG3RD concept proposes the application of satellite technology for surveillance, navigation, and data link communication with aircraft, as well as continuation of VOR-DME navigation facilities, VHF voice communication facilities, and the ground-based Discrete Address Beacon System of the Upgraded Third Generation System.

4. STOL-PORTS AND STOL-STRIPS

Short takeoff and landing aircraft (STOL) have a number of unique performance characteristics of particular interest to the Air Traffic Control System. These include: landing and takeoff within relatively short distances, approach gradient up to 7.5^{o}, climb gradient up to 10^{o}, ability to vary speed readily, high maneuverability at low speed, close-in curved approach capability, and small noise footprint. 11/

The mission of the STOL aircraft basically is in the field of short haul air service. Typical stage lengths are under 500 miles. STOL air service will need to operate into minimum sized landing and takeoff STOL-ports and STOL-strips, as well as airports used by larger aircraft. STOL air services should be capable of meeting Category I, Category II, and eventually, Category III requirements.

At a conventional airport, STOL runways may be a portion of an existing runway or a special STOL runway may be constructed. Simultaneous but separate operations of large aircraft and STOL aircraft at the same airport will be needed to reduce STOL-induced traffic congestion and delay. For STOL operations at locations removed from conventional takeoff and landing (CTOL) airports, a STOL-port is needed.

11/ Glen A. Gilbert, "STOL and ATC," paper presented at the Air Traffic Control Association 21st Annual Meeting and Technical Program, September 28-30, 1976, Miami, Florida.

The STOL impact on ATC workload is greater by roughly a factor of five than CTOL. The reason is that STOL aircraft are short-base dedicated and during a given day will tend to average nearly 50 operations (takeoffs and landings) compared to 6 to 8 for trunk air carriers and 8 to 12 for regional air service.

An additional ATC related problem with mixed CTOL and STOL operations is landing time intervals given current IFR separation intervals. While a 3-mile CTOL spacing results in about a one minute landing time interval, the same spacing of STOLs produces a landing time interval of around 3 minutes because of their much slower approach speed. Mixed operations may reduce capacity to only 1/3 of CTOL capacity unless separation minimums are reduced. STOL operations, therefore, must be independent of CTOL operations because their increased usage will raise demand by a factor of 5 per aircraft and lower capacity by two-thirds per operation. This means separate STOL-strips at CTOL airports and also satellite airports.

5. AIRPORT SURFACE TRAFFIC CONTROL (ASTC)

Control of aircraft on final approach and initial departure paths and on the surface of the airport is currently managed manually by controllers stationed in the cab of the airport control tower. The location of aircraft is obtained by the controllers visually, when weather permits, or by pilot position reports via voice radio when the controllers are unable to see. The only controller aids currently available are the analog ground surveillance radar (ASDE-2) at eight airports, television cameras at a few airports to cover blind spots due to physical obstructions, and the Airport Surveillance Radar (ASR) which covers airborne aircraft between one and sixty miles of the airport.

The proposed system improvement is a new analog ground surveillance radar (ASDE-3). It will be a "skin tracking" radar, like ASDE-2, with a bright scan converted plan position indicator (PPI) display. While ASDE-3 will meet the needs of most airports, a more sophisticated system is warranted at the major airports. This new system, Tower Automated Ground Surveillance (TAGS), will likely be cooperative, locating each aircraft by receiving a beacon signal transmitted by the aircraft at several receivers and solving trilateration equations. The sensor will use the existing ATCRBS transponder on-board each aircraft but will be DABS compatible.

When the cab controllers cannot see the airport surface (during Category II weather), they must rely upon pilot position reports to get a picture of the surface traffic. These reports saturate the radio channel and also frequently come late. Both of these

problems diminish the capacity of ground control and produce overall system delay. While ASDE restores virtually all the capacity lost to local control, such is not the case with ground control. Even with an ASDE presentation, the use of position reports to provide the identity required for communication continues to bog down the ground controller.

To date, the problem has been most critical at O'Hare. However, as more aircraft equip with Category II and other major airports install two independent Category II runways, the capacity of ground control becomes a problem.

6. ADVANCED JET ENGINES RETROFIT

The anticipated savings in specific fuel consumption of advanced jet engines is a result of gradual improvements to existing technologies rather than drastic new technologies. This series of improvements, while mildly significant individually, produces significant results collectively. The following improvements (with possible impacts) are considered possible by the mid-1980's. 12/

o	Reduce compressor and turbine tip clearance	Up to 4 Percent
o	Improved (labyrinth) seal designs	Up to 2 "
o	More efficient combustion	Up to 1 "
o	Other reductions in pressure losses	Up to 1 "
o	Improved turbine cooling	Up to 1 "
o	Other	Up to 1 "
	TOTAL	5 to 10 Percent

There are larger potential improvements from more basic design changes. NASA has suggested that raising the turbine entry temperature for cruising by about 280°C, the pressure ratio to 40, and the bypass ratio to 10.4, should give a 1985 turbofan an 8 percent reduction in specific fuel consumption as compared with the best models currently in service (e.g., CFM56/JT10D).

7. DIGITAL ELECTRONIC PROPULSION CONTROL SYSTEMS (DEPCS) FOR TURBINE ENGINES

A prime reliable electronic mini or micro computer capable of meeting the control requirements of the advanced turbine engines will do away

12/ K. G. Wilkinson, "The Technology and Economics of Air Transport in the Next Phase," Aeronautical Journal, March 1976, p. 109.

with the need for the relatively less efficient hydromechanical control systems in use today. Further, the DEPCS could monitor fuel flow in a real time environment with a closed loop design, thereby removing human decision making from the control process except by exception. Control system costs would be lower, aircraft weight less, and fuel usage optimal with respect to each aircraft type and age. The Throttle Energy Management System studied by Lockheed-Georgia is a forerunner of the DEPCS. 13/

8. ACTIVE CONTROLS

In most current commercial aircraft, mechanical and electronic devices, in combination with the aerodynamic control surfaces, augment inherent stability and control characteristics. Considerable current work aims at going significantly beyond stability augmentation by using aerodynamic surfaces in combination with advanced flight computers and electro-hydraulic systems to improve economics, smooth the passenger's ride, reduce terminal area noise, and ease congestion. This emerging technology is becoming known as active controls technology (ACT). Active controls might improve economics by reducing structural weight, lengthening fatigue life, and improving aerodynamic performance. The Advanced Transport Technology (ATT) system studies have looked at relaxing static stability, controlling maneuver load, actively suppressing flutter, and alleviating gust loads. 14/

Active controls permit maneuvering load control with aft center of gravity gains from relaxed static stability. Associated weight drag and aircraft size. The potential fuel savings is nearly 4 percent. 15/ If 30 percent of the air carrier fleet have active controls by 1990, then the resultant fuel savings will be 1.2 percent. Retrofit is difficult, since the aircraft must be designed for active controls.

9. COMPOSITE MATERIALS RETROFIT

The high strength-to-weight ratio of composite materials such as graphite-epoxy will significantly reduce structural weight and, thereby,

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13/ Lockheed-Georgia Company, Independent Research and Development Report for 1974 and Program Plan for 1975, Report No. LG75ER0026, March 1975, Volumes I and II.

14/ Dal V. Maddalon, "Rating Aircraft on Energy," Astronautics and Aeronautics, December 1974, p. 37, and Richard S. Sevell, "Technology, Efficiency, and Future Transport Aircraft," Astronautics and Aeronautics, September 1975, pp. 36-37.

15/ "Advanced Subsonic Transport Technology Assessment," Astronautics and Aeronautics, August 1972, pp. 26-55.

fuel consumption. Cost per pound, durability, and maintainability of composites remain uncertain. Early use of composites can be expected for fairings, cowl doors, and floor panels by 1982. By 1985, composite usage will include control surfaces, leading edges, nacelle cowling, and tail surfaces. 16/

Compared to an aluminum airplane, an aircraft employing about 10 percent composite structure would reduce fuel needed about 3 percent while a 40 percent composite structure could reduce fuel consumption up to 11 percent. 17/ If 30 percent of the air carrier fleet consisted of aircraft which were of 40 percent composite structure, then the increase in RTM/G would be 3.3 percent. Composite retrofit is possible for select structures (e.g., fairings, secondary body structures), but the real gains will only be obtained when the primary structure is largely of composite materials and new structural concepts.

10. SUPERCRITICAL AIRFOIL

As an aircraft approaches Mach 1, strong shock waves form which increase drag. Supercritical aerodynamics can benefit aircraft by either increasing the speed at which this drag rise occurs or by reduced sweep and higher aspect ratio which fly at current speeds.

The improved transonic or supercritical airfoil originally developed by Richard T. Whitecomb of NASA Langley Research Center appears to be one of those developments for which almost all aspects are favorable. It can offer a substantially higher Mach number for initial drag divergence for a given airfoil thickness, an excellent structural shape, and high maximum lift coefficient.

The main characteristic of the new airfoils is an increase in the loading toward the rear of the airfoil due to aft camber. Carrying this aft load permits reducing the pressure coeeficient at and aft of the airfoil crest which in turn raises the drag divergence Mach number.

An aircraft designer could use the supercritical airfoil to maintain current or even lower cruise speeds and either less wing sweeps to increase maximum lift coefficient and, for a given aerodynamic aspect ratio, decrease wing weight, or increase the wing thickness

16/ Lockheed-California Company, Cost/Benefit Tradeoffs for Reducing the Energy Consumption of the Commercial Air Transportation System, NAS2-8612, April 7, 1976, p. 54.

17/ Dal V. Maddalon, "Rating Aircraft on Energy," Astronautics and Aeronautics, December 1974, p. 37.

ratio to significantly lighten the wing. The latter course would increase airfoil profile drag enough to negate some of the fuel savings. In practice, combinations of thickness increase and wing-sweep reduction would give the optimum configuration for any design speed. Significant benefits can be obtained if the design cruise speed were high enough to require wings thinner than about 12 percent, or sweepback angles greater than about 20 degrees with current airfoils. 18/

Aircraft cruise could be raised by 0.03M at a constant wing weight for a 4.5 percent fuel savings. Reductions in weight could also be obtained or increases in thickness could permit using higher aspect ratios with less weight penalty. A higher aspect ratio would raise the lift drag ratio and reduce fuel consumption as much as 10 percent. Assuming that 30 percent of the air carrier fleet have supercritical airfoils with high aspect ratios by 1990, the resultant energy conservation will equal 3.0 percent. A wing retrofit program is possible; however, the new near term (NNT) aircraft option, if utilized, would likely obviate any wing retrofit program.

11. REPLACE AIRCRAFT WITH NEW NEAR TERM (NNT) AIRCRAFT

Several of the previously discussed engine and aircraft technologies have been combined into a potential new near term aircraft which could be available by the early 1980's. Tentative plans are to incorporate such features as new engine technology (JT10D/CFM56), winglets, supercritical airfoils, active controls, and composites. Laminar flow control is not planned for this aircraft due to existing technological problems associated with its application.

As a generic type, the RECAT 19/ version of the NNT was described as a 200 passenger aircraft using composite materials in the primary structure, advanced technology engines, stability augmentation, and a high-aspect ratio wing with supercritical airfoil sections. The flyaway cost of the aircraft was estimated at under $20 million. The seat miles per gallon value for the NNT was estimated at 46.25 versus 33.04 for the B707/DC-8 and 31.92 for the B727.

The Boeing version of such an aircraft is referred to as the Boeing 7X7 while the Douglas Aircraft version is the DC-C-200. These

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18/ Richard S. Shevell, "Technology, Efficiency, and Future Transport Aircraft," Astronautics and Aeronautics, September 1975, pp. 37-38.

19/ United Technologies Research Center, Cost/Benefit Tradeoffs for Reducing the Energy Consumption of Commercial Air Transportation, Report No. R76-912036-16, June 1976, p. 97.

aircraft are expected to replace the present B707 and DC-8 aircraft in the fleet and to also be competitive replacements for B727-200.

Based on the projected air carrier fleet in Table 12, the replacement of all B707 and DC-8 aircraft plus one-half of all B727 aircraft would result in 30 percent of the 1990 fleet consisting of B7X7/DC-X-200 aircraft.

By reference to already reported impacts for those features to be incorporated in the new aircraft, it is possible to estimate the fuel savings it will produce.

New Engines	10 Percent
Winglets	3 "
Supercritical Airfoils	10 "
Active Controls	4 "
Composites	11 "
New Aircraft	38 Percent

This estimate is consistent with the expected improvement reported by the studies of new near term aircraft. 20/ With an expected 30 percent of the fleet by 1990, fuel savings and increases in RTM/G will equal 11.4 percent.

12. STOL AIRCRAFT

The growing problem of congestion on the ground and in the air can be partially offset by a more efficient interfacing between the various transport modes. The current 30 passenger or less commuter aircraft serves the short-haul market. An 80-100 passenger STOL could alleviate congestion in select markets (e.g., New York area) and reduce the number of operations per passenger by replacing smaller commuter aircraft.

20/ M. D. Ardema, M. Harper, C. L. Smith, M. H. Waters, and L. J. Williams, Conceptual Design of Reduced Energy Transports, Journal of Aircraft, August 1976, pp. 545-550, and Richard S. Shevell, "Technology, Efficiency, and Future Transport Aircraft," Aeronautics and Aeronautics, September 1975, pp. 36-42.

13. LARGE AIR CARGO TRANSPORTS

The Lockheed-Georgia Company has conducted a number of studies concerning air cargo transports far larger than the B747F. 21/ One such aircraft, the Spanloader (flying wing), could carry a 275 ton payload 5,000 nautical miles at transport costs approaching that of intercity trucks. A less radical design, however, could carry a 50 to 180 ton payload and would incorporate advanced technology (new engines, supercritical wings, etc.). Such an aircraft would not likely be available, however, until 1986 or later.

21/ Lockheed-Georgia Company, Independent Research and Development Report for 1974 and Program Plan for 1975, Report No. LG75ER-0026, March 1975, Volumes I and II.

CHAPTER IV

SYNTHESIS AND EVALUATION OF LONG RUN POLICY OPTIONS

The thirteen long run policy options generated in the preceding chapter must now be synthesized and evaluated into a coherent long run program for aviation energy conservation. Each option must also be assessed as to its impact on the other aviation variables of safety and environmental impacts. The Energy Policy Evaluation Model of Table 1 is utilized to translate the impact of each option on fuel conservation to an impact on the target variable, RTM/G. After evaluating the options based on other aviation objectives, a Long Run Energy Conservation Program is developed. The Short, Intermediate, and Long Run Programs are processed in a final synthesis which appears in Volume III, and produces a comprehensive Aviation Energy Conservation Program.

The approach utilized in Chapter II is retained: the thirteen options are partitioned according to their impact upon the variables of the Energy Policy Evaluation Model, then the Method/Options analysis is pursued. A summary of the Method of RTM/G increase and the options under that method are presented in Table 13. Following the Method/Options Analysis, the other aviation objectives are evaluated for the energy policy options and the final result of the chapter is the list of acceptable options, their impacts, and timeframe.

1. METHOD: REDUCE GALLONS PER HOUR BY REDUCING DELAY

   OPTIONS:
   - o DABS/ATARS
   - o Post-UG3RD ATC
   - o ASTC
   - o STOL-Ports and STOL-Strips

   The primary fuel consumption gains from DABS/ATARS and Post-UG3RD ATC will result from more accurate identification of aircraft through four dimensions (latitude, longitude, altitude, speed). These gains may then be translated into tighter sequencing and reduced separations. The gains from reduced separations cannot all be attributed to DABS and/or ATC since a major contribution is made by the Wake Vortex Avoidance System (WVAS). Therefore, it is estimated that

TABLE 13

LONG RUN POLICY OPTION GROUPINGS

REDUCE GALLONS PER HOUR BY REDUCING DELAY

- o DABS/ATARS
- o Post-UG3RD ATC
- o ASTC
- o STOL-PORTS and STOL-STRIPS

REDUCE GALLONS PER HOUR AND HOURS PER MILE (Gallons Per Mile) BY USING IMPROVED AIRCRAFT TECHNOLOGY

- o Active Controls
- o Composite Materials
- o Supercritical Airfoils
- o Replace Aircraft With New Near Term Aircraft
- o STOL Aircraft
- o Large Air Cargo Transports

REDUCE GALLONS PER MILE BY USING IMPROVED ENGINE TECHNOLOGY

- o Advanced Jet Engines
- o Digital Electronic Propulsion Control

REDUCE GALLONS PER MILE BY USING IMPROVED OPERATIONAL SYSTEM

- o MLS

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overall gains from reduced separations will be 15 percent in capacity and 1.5 percent in fuel. One percent is attributed to WVAS, .2 percent to DABS, and .3 percent Post-UG3RD ATC. (a)

Ground control under adverse weather conditions such as Category II and Category III must rely exclusively on voice communications. During peak demand, this manual technique of creating a picture of ground traffic introduces ground delay which in turn translates into airborne delay. Although presently not a critical problem, except at one or two major airports, the potential as a delay inducing element is real and substantial. Fuel gains in the present system from ASTC use would be no more than .1 percent.

The mixing of STOL and CTOL aircraft on the same runway reduces runway acceptance rates due to the slower flying aircraft (same problem as mixed GA-air carrier aircraft). With fixed IFR separations, the slower aircraft force slower air speeds on all other aircraft in the queue and, thereby, lower the number which may be accommodated. By creating separate STOL runways and satellite airports, the system can gain capacity and lower fuel consumption by as much as one percent with 0.5 percent due to reduced separations and 0.5 percent due to the new usable runways. (b) Since reduced separation is

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Note (a): For the long run options related to Air Traffic Control, the assumption was made that total system implementation would produce up to a 40 percent reduction in delay related fuel consumption (7.4 percent X .4 = 3.0 percent potential savings). The nonoverlapping portions of the short and intermediate run options of FAD (.09 of 1.7 percent), WVAS (1.0 percent), and Control Automation (.6 percent) were removed from the total (3.0 percent), leaving .5 percent to be allocated over DABS/ATARS and Post-UG3RD ATC on a 40-60 basis.

Note (b): Under a mixed CTOL and STOL operation with half of the demand devoted to STOL aircraft, single runway capacity will be roughly 40 operations per hour. The addition of a STOL runway would allow 60 CTOL and 60 STOL operations per hour (assuming reduced separation standards for STOL) for a 200 percent increase in capacity. If only 5 percent of this increase is translated into fuel savings by increasing capacity when additional capacity is needed, the resultant fuel savings will be near one percent. Half of this gain is due to reduced separations and half to a new STOL-Strip.

measured in other options and since the short run option of GA runways is virtually identical to STOL-strips, the net gain to the system from STOL-ports and STOL-strips is estimated at .3 percent. The implementation of the options are assumed to be as follows: 1982-1986 for DABS/ATARS, 1988-1990 for Post-UG3RD ATC, 1982-1985 for ATSC, and 1982-1990 for STOL-Ports/Strips. S-curves are utilized to timeframe the impacts.

TIME FRAME: DELAY REDUCING OPTIONS

	1982	1983	1984	1985	1986	1987	1988	1989	1990
	Cumulative Impact on RTM/G								
o DABS/ATARS	.01	.06	.14	.19	.20	.20	.20	.20	.20
o Post-UG3RD	0	0	0	0	0	0	.05	.25	.30
o ASTC	.01	.05	.09	.10	.10	.10	.10	.10	.10
o STOL-Ports/Strips	.01	.02	.05	.11	.18	.24	.28	.29	.30

2. METHOD: REDUCE GALLONS PER MILE BY USING IMPROVED ENGINE TECHNOLOGY

OPTIONS: o Advanced Jet Engines

o Digital Electronic Propulsion Control (DEPC)

Evolutionary improvements to existing turbofan jet engines may improve specific fuel consumption 10 percent by 1990. Some of the improvements which will collectively produce this gain include: reduced compressor and turbine tip clearance, improved seal designs, and raised turbine entry temperature. These engines would not be available until 1985. If 20 percent of the 1990 fleet is retrofitted with these advanced jet engines, overall RTM/G would rise by 2 percent.

An electronic computer can meet the control requirements of advanced turbine engines and thereby replace the less efficient hydromechanical control systems of today. Use of mini and micro-computers for this purpose will lower aircraft weight and optimize fuel usage per aircraft producing total fuel consumption savings of up to 2 percent by 1990. The DEPC is assumed to be introduced in 1982 and utilized by the entire air carrier fleet by 1990.

TIME FRAME: ENGINE TECHNOLOGY OPTIONS

	1982	1983	1984	1985	1986	1987	1988	1989	1990
	Cumulative Impact on RTM/G								
o Advanced Jet Engines	0	0	0	0	.12	.57	1.41	1.88	2.0
o DEPC	.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.0

3. METHOD: REDUCE GALLONS PER HOUR AND HOURS PER MILE (GALLONS PER MILE) BY USING IMPROVED AIRCRAFT TECHNOLOGY

OPTIONS:
- o Active Controls
- o Composite Materials
- o Supercritical Airfoils
- o Replace Aircraft with New Near Term Aircraft
- o STOL Aircraft
- o Large Air Cargo Transports

The use of advanced flight computers and electrohydraulic systems to improve operating performance and aerodynamic control, known as active controls, derives from the ability to maneuver load control with aft CG gains plus the gains associated with reduced wing weight, tail weight drag, and aircraft size. Altogether, a reasonable estimate of fuel consumption reduction due to active controls, using 30 percent of the 1990 fleet, is 1.2 percent. Since new aircraft are treated as a separate option, this option implies a retrofit/modification program to existing aircraft. The same implication exists from the next two options: composite materials and supercritical airfoils.

The aluminum era of aircraft construction is nearing an end. New, lighter weight materials such as the composite graphite-epoxy have a very high strength relative to weight and are going to help reduce aircraft weight and improve fuel consumption. By 1985, use of composites may include control surfaces, leading edges, Nacelle cowling, and tail structure. Conversion of aircraft construction to 40 percent composite structure, a realistic objective for new aircraft, would reduce fuel consumption by as much as 11 percent. A 10 percent secondary structure composite retrofit program would

save about 3 percent in fuel usage. If 30 percent of the 1990 fleet were subject to 10 percent retrofit, the fleet savings would be 0.9 percent. Such a program could be begun as early as 1982 and would for the most part be oriented towards aircraft purchased in the seventies and thereafter.

As an aircraft approaches Mach one, strong shock waves form which increase drag. Supercritical aerodynamics can benefit aircraft by either increasing the speed at which the drag rise occurs, by reducing wing weight, or by improving structural efficiency through wings of reduced sweep and higher aspect ratio which fly at current speeds. Most gains by 1990 due to the supercritical airfoil are expected from the latter application. Commercially successful transonic and supersonic aircraft as a significant proportion of the air carrier fleet are not expected until post-1990. Under a modification program involving placing supercritical airfoils on 30 percent of the 1990 fleet, the resultant increase in RTM/G would equal 3.0 percent. Note that the composite and supercritical wing retrofit program for 30 percent of the 1990 fleet together save 6.0 percent in fuel usage.

The engine and aircraft technology options of this section have been incorporated into a new design aircraft which is primarily targeted at replacement of the B707/DC-8 aircraft now in the fleet plus a significant portion of the B727-200 fleet. The new near term aircraft, B7X7 or DC-X-200, would include as features: new engines such as the JT10D or CFM56, winglets, supercritical airfoils, active controls, and composites. In combination, these plus other less dynamic improvements in design are expected to produce an aircraft which will lower fuel consumption by 38 percent over present day aircraft. If the B707/DC-8's were all replaced plus half of the B727's, the resultant replacement of 839 aircraft in the 1990 fleet by B7X7/DC-X-200's (27.5 percent of the fleet), would lower fuel consumption and raise RTM/G by 10.4 percent in 1990.

The STOL aircraft option would relieve congestion in crucial areas (e.g., New York); however, this aspect of the introduction of STOL aircraft has been captured by the option "STOL-Ports and STOL-Strips." The replacement of 30 passenger commuters by 80-100 passenger STOL aircraft could be expected to reduce total airport operations slightly and thereby reduce total delay. This impact would be on the order of 0.2 percent or so, but this figure is conjectural. Further study of the effect of STOL aircraft on the NAS is sorely needed. An important side benefit of STOL aircraft, not evaluated herein, is that groundside delay and the relatively extravagant usage of fuel by automobiles in intercity travel would be reduced. Passenger travel by automobiles accounts for 52.6 percent of total petroleum use in transportation. Diversion from auto to STOL might be system energy-efficient, depending upon the relative energy intensiveness of the two transport modes. This

substitution impact is difficult to quantify at this point and is deleted from the analysis. The STOL impact on RTM/G may well be understated. The impact is presumed to begin in 1985. The small benefits from STOL-Ports beginning in 1982 is due to their usage by GA aircraft.

The Large Air Cargo Transport could be introduced in 1986 with a RTM/G value of up to 3.4. It would carry up to a 275 ton payload and, while its aircraft gallons per mile would be an incredible 80.9 (from Table 4, the B747 uses 7.4 gallons per mile carrying 22.1 tons), for a "smaller" version carrying only 50 tons the gallons per aircraft mile value would be 14.7. Thus, the improvement over the B747F would be about 25 percent in total. It is assumed that only 10 percent of the all-cargo tonnage capacity (not aircraft) is replaced between 1986 and 1990 for a system increase of 0.3 percent in RTM/G.

Each of the first four aircraft technology options were timeframed between 1982 and 1990 with an S-curve approach. It was realized that production could be maintained at a constant rate by devoting a specific number of production lines to production of new aircraft or modification of old aircraft. However, it was felt that demand, not supply, would dominate purchase patterns and tend more toward an S-curve result rather than a linear relationship (equal gains each year leading stepwise to the 1990 impact).

TIME FRAME: AIRCRAFT TECHNOLOGY OPTIONS

	1982	1983	1984	1985	1986	1987	1988	1989	1990
				Cumulative Impact on RTM/G					
Active Controls	.04	.08	.20	.44	.76	.96	1.12	1.16	1.20
Composite Materials	.10	.20	.50	1.10	1.90	2.40	2.80	2.90	3.00
Supercritical Airfoils	.10	.20	.50	1.10	1.90	2.40	2.80	2.90	3.00
New Near Term Aircraft	.35	.68	1.73	3.81	6.59	8.32	9.71	10.05	10.40
STOL Aircraft	0	0	0	0.01	0.03	0.10	0.17	0.19	0.20
Large Air Cargo	0	0	0	0	0.02	0.09	0.21	0.28	0.30

4. METHOD: <u>REDUCE GALLONS PER MILE BY USING IMPROVED OPERATIONAL SYSTEMS</u>

OPTION: o Microwave Landing Systems (MLS)

The Microwave Landing System is a replacement system for the current Instrument Landing System (ILS). MLS embodies three major categories of measurement guidance: angle guidance, flare guidance, and range measurement. The primary MLS fuel impact will be a result of different glidepaths for different aircraft, thus permitting more optimal descent techniques.

The short run option of optimal descent, discussed in Volume I of this study, is expected to raise RTM/G by 2.6 percent with .6 percent achievable in the short run without MLS and 2.0 percent MLS dependent in the long run.

The impact is estimated for each time period by using an S-curve.

TIME FRAME: MLS

	1982	1983	1984	1985	1986	1987	1988	1989	1990
MLS	.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00

POTENTIAL PROGRAMS

The preceding thirteen energy policy options for the long run must be assessed as to their impact on goals other than fuel conservation. The effects of each on safety and the environment are critical. Substantial negative impacts in either area would mitigate against inclusion of the option in the Aviation Energy Conservation Program developed in Volume III of this report. The perceived impact of the long run options presented in Chapter III and analyzed in Chapter IV on safety, noise, and emissions are presented in Table 14. No negative effects are anticipated and none of the options are eliminated due to detrimental effects on other aviation objectives.

Thus, all long run policy options are carried forward and presented with their timeframes in Table 15. As has been stated previously, these options are not independent. The adoption of one option may mitigate against the adoption of another. Within the long run option set, the options of advanced jet engines, active controls, composite materials, and supercritical airfoils might compete with the option of new near term aircraft since they could all likely be incorporated in such an aircraft.

TABLE 14

INTERACTION OF LONG RUN ENERGY OPTIONS

WITH OTHER POLICIES

Programs	Safety	Noise	Emissions
A. AIR TRAFFIC CONTROL			
1. DABS/ATARS	+	0	0
2. Post-UG3RD ATC	+	0	0
3. MLS	+	+	0
B. AIRPORTS			
1. STOL-Ports and STOL-Strips	+	+	0
2. ASTC	+	0	0
C. ENGINE TECHNOLOGY			
1. Advanced Jet Engines Retrofit	0	+	+
2. Digital Electronic Propulsion Control	0	0	0
D. AIRCRAFT TECHNOLOGY			
1. Active Controls	0	0	0
2. Composite Materials	0	0	0
3. Supercritical Airfoils	+	0	0
4. New Near Term Aircraft	+	+	+
5. STOL Aircraft	+	+	+
6. Large Air Cargo Transports	+	+	+

+ = Beneficial Effect
- = Potential Deleterious Effect
0 = Neutral Net Effect

TABLE 15

LONG RUN ENERGY CONSERVATION POLICY SET:
MAXIMUM CUMULATIVE IMPACT ON RTM/G

Programs	1982	1983	1984	1985	1986	1987	1988	1989	1990
A. AIR TRAFFIC CONTROL									
1. DABS/ATARS	.01	.06	.14	.19	.20	.20	.20	.20	.20
2. Post-UG3RD ATC							.05	.25	.30
3. MLS	.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00
B. AIRPORTS									
1. STOL-Ports and STOL-Strips	.01	.02	.05	.11	.18	.24	.28	.29	.30
2. ASTC	.01	.05	.09	.10	.10	.10	.10	.10	.10
C. ENGINE TECHNOLOGY									
1. Advanced Jet Engines					.12	.57	1.41	1.88	2.00
2. Digital Electronic Propulsion Control	.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00
D. AIRCRAFT TECHNOLOGY									
1. Active Controls	.04	.08	.20	.44	.76	.96	1.12	1.16	1.20
2. Composite Materials	.11	.22	.55	1.21	2.09	2.64	3.08	3.19	3.30
3. Supercritical Airfoils	.10	.20	.50	1.10	1.90	2.40	2.80	2.90	3.00
4. New Near Term Aircraft	.38	.75	1.90	4.18	7.22	9.12	10.64	11.02	11.40
5. STOL Aircraft	0	0	0	.01	.03	.10	.17	.19	.20
6. Large Air Cargo Transports	0	0	0	0	.02	.09	.21	.28	.30
TOTAL	.77	1.63	4.09	8.80	15.16	19.62	23.80	25.34	26.30

Note: These options are not independent. The total, therefore, overstates the achievable result for 1982-1990 and is provided as an upper bound only. This problem is addressed in Volume III of this report.

The total values shown at the bottom of Table 15 are not obtainable due to the interactions. The total is provided to indicate an upper bound on the impact of the options.

CHAPTER V

SUMMARY

The purpose of Volumes I and II of this report is to identify and analyze policy options which would assist in the effort to lower fuel consumption and improve fuel efficiency in aviation. The options were grouped by the expected timeframe for implementation: short, intermediate, and long term. The short term options were the basis of study in Volume I, while the intermediate and long term options were included in this volume. The output of these two volumes is carried forward to Volume III where cross-impact analysis identifies interdependencies and assists in the development of a proposed Aviation Energy Conservation Program.

Within each timeframe, various subgroupings of options were identified and analyzed: Air Traffic Control, Airports, Operating Procedures, Engine Technology, and Aircraft Technology. Each of these subgroupings has effect over the entire timeframe of 1977 to 1990. Each will be discussed briefly in this summary.

The present air traffic control system is referred to generally as the third generation system. Most of the air traffic control options, as listed in Table 16, are component parts of the upgraded third generation system. Over the next few years, expansion of FAD, Wake Vortex Avoidance Systems, and RNAV could produce savings in fuel consumption up to 2.10 percent. The bulk of this result would be derived from an aggressive program to implement FAD at the major airports. Control automation would produce fuel savings in the intermediate term while DABS/ATARS and MLS will be major factors in the long run. Near the end of the long term, the post-UG3RD ATC system will begin to have an effect on fuel consumption as it is introduced.

Significant gains from short term airport options (Table 17) result from new runways and snow-ice equipment. The dominant effect is attributed to new GA runways at hub airports. Towing aircraft has the potential to greatly reduce fuel consumption due to delay and could begin to impact by 1979 if actively pursued.

Changes in operating procedures (Table 18) are all short run. Restraining capacity by altering fleet consumption or reseating aircraft are significant options as is the effect of the remaining operational options to produce an optimal fuel-efficient flight path from takeoff to touchdown.

TABLE 16

AIR TRAFFIC CONTROL OPTIONS AND IMPACTS - 1977-1990

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
FAD	.85	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
Wake Vortex Avoidance Systems	.08	.20	.36	.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
RNAV		.20	1.00	1.81	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Control Automation			.12	.50	.60	.60	.60	.60	.60	.60	.60	.60	.60	.60
DABS/ATARS						.01	.06	.14	.19	.20	.20	.20	.20	.20
MLS						.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00
Post-UG3RD ATC												.05	.25	.30
TOTAL	.93	2.10	3.18	4.86	5.30	5.37	5.49	5.77	6.22	6.77	7.10	7.42	7.69	7.80

TABLE 17

AIRPORTS OPTIONS AND IMPACTS - 1977-1990

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Temporary Construction Runways	.15	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
GA Runways	.54	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Snow-Ice Equipment	.06	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
Tow Aircraft			.62	3.03	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
Fog Dispersal			.02	.08	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
STOL-Ports						.01	.02	.05	.11	.18	.24	.28	.29	.30
ASTC						.01	.05	.09	.10	.10	.10	.10	.10	.10
TOTAL	.75	1.50	2.14	4.61	5.30	5.32	5.37	5.44	5.51	5.58	5.64	5.68	5.69	5.70

TABLE 18

OPERATING PROCEDURE OPTIONS AND IMPACTS - 1977-1990

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Simulators	.10	.10												.10
Restrain Capacity/Reseat	.55	1.10												.30
Reduce Tankering	.15	.30												.20
Taxi on Fewer Engines	.10	.20												.20
Load to Aft CG	.10	.20												.16
Climb Procedures	.08	.16												.70
Optimum Cruise	.35	.70												.65
Optimum Altitude	.32	.65												.60
Optimum Descent	.30	.60												
TOTAL	2.05	4.01												4.01

The analysis of engines (Table 19) assumes the JT10D/CFM56 technology by 1982 with possible retrofit options and further evolutionary advances in engine technology by the mid-1980's. New technological breakthroughs such as the variable cycle engine for the second generation SST are not assumed for subsonic aircraft.

The one area with the greatest potential for assisting in fuel conservation by 1990 is that of aircraft technology (Table 20). Winglets, Aft Body Modifications, On-Board Performance Computers, Active Controls, Composite Materials, and Supercritical Airfoils can all significantly lower fuel consumption. Whether modifications to present aircraft, derivative aircraft, or new near term aircraft are taken as the optimal strategy will be explored in Volume III.

An actual forecast of fuel consumption based on Tables 16-20 cannot accurately be made until the cross-impact analysis of Volume III is completed. A preliminary estimate can be put forth, however, to indicate the approximate magnitude of the eventual value of RTM/G. In Table 16, the options are basically independent. Thus, the ATC options could be expected to raise RTM/G by around 4.5 percent by 1980, 6.0 percent by 1985, and 7.5 percent by 1990. The airport options of Table 17 do have some interdependencies. Each of temporary construction runways, GA runways, and STOL-ports affect each other. Taking the highest impact number of the three RTM/G could rise by 4.2 percent by 1980, 5 percent by 1985, and 5.1 percent by 1990. Note that the Tow Aircraft option is the fundamental gain producing option for the airport option set. The operating procedures of Table 18 are not strongly interdependent and a gain of 4.0 percent by 1980 and thereafter is quite likely. Tables 19 and 20 have strong interdependencies both intratable and intertable. If an engine retrofit program on existing aircraft is undertaken, purchases of derivative and/or new near term aircraft will be reduced and/or delayed. If the new near term aircraft is included, retrofits and derivative aircraft would be similarly affected. Taking this latter case, a rough estimate of the impact of the combined engine and aircraft technology options would be about 4 percent by 1980, 10 percent by 1985, and 15 percent by 1990. These figures are upper bounds on the actual figures forecasted in Volume III. Taking the above as a guide, however, RTM/G would rise by about 15 percent by 1980, by 25 percent by 1985, and by 30 percent by 1990. The striking increases in RTM/G occur in the 1980's, however. The dependence of the 30 percent or so increase in RTM/G on technology options, in particular the new near term aircraft, is consistent with the historical high-technology nature of aviation. The realization of the goal may well depend upon the ability of the National Aviation System in general, and the airlines specifically, to pursue these high-technology, energy-conserving solutions. This issue will be readdressed in Volume III.

TABLE 19

ENGINE TECHNOLOGY OPTIONS AND IMPACTS - 1977-1990

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Performance Movement			.12	.57	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
JT8D Retrofit			.58	1.16	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
JT10D Retrofit			1.66	3.32	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
Advanced Jet Engines										.12	.57	1.41	1.88	2.00
Digital Electronic Propulsion						.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00
TOTAL			2.36	5.05	7.41	7.47	7.54	7.74	8.14	8.80	9.58	10.69	11.23	11.41

TABLE 20

AIRCRAFT TECHNOLOGY OPTIONS AND IMPACTS - 1977-1990

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Derivative Aircraft			.79	3.71	4.47	4.47	4.47	4.47	4.47	4.47	4.47	4.47	4.47	4.47
Lighter-Than-Air Vehicles			.10	.47	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
Winglets			1.27	2.15	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Wingtip Extensions			1.27	2.15	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Aft Body Modifications			2.10	3.56	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98
On-Board Performance Computers			.25	1.23	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Active Controls						.04	.08	.20	.44	.76	.96	1.12	1.16	1.20
Composite Materials						.11	.22	.55	1.21	2.09	2.64	3.08	3.19	3.30
Supercritical Airfoils						.10	.20	.50	1.10	1.90	2.40	2.80	2.90	3.00
New Near Term Aircraft						.38	.75	1.90	4.18	7.22	9.12	10.64	11.02	11.40
STOL Aircraft									.01	.03	.10	.17	.19	.20
Large Air Cargo Transports										.02	.09	.21	.28	.30
TOTAL			5.78	1.327	17.52	18.15	18.77	20.67	24.46	29.54	32.83	35.54	35.63	36.92

APPENDIX

SUPPLEMENTAL INTERMEDIATE AND

LONG RUN OPTIONS

APPENDIX

SUPPLEMENTAL INTERMEDIATE AND LONG TERM

POLICY OPTIONS

There were several energy policy options studied during the early stages of this project which were subsequently filtered for a number of reasons. Some are beyond the timeframe under consideration, some have negligible effects on RTM/G, while others are not compatible with alternative aviation objectives.

Altogether, 19 options were identified and deleted in this first screening of options. This does not preclude the possibility that one or more of these options might later prove viable. It simply means that the probability of them being significant appears very low in the time period studied.

1. REQUIRE TRANSPONDERS AND ALTITUDE REPORTING CAPABILITY ON ALL AIRCRAFT

   Present FAA plans are to require this equipment in positive control airspace consisting of Group I and II TCA locations and in controlled airspace of the 48 states above 12,500 feet. This proposal is to extend the requirement to all aircraft. This will facilitate flow control at all controlled airports and increase the safety factor.

2. REMOTE PARKING PADS

   Ramp congestion and aircraft holding to wait for gates can be relieved by the construction of remote parking pads, using mobile transporters to move passengers from the terminal to the pads. Aircraft should be required to use these remote pads when terminal gates are occupied and waiting times exceed 5 minutes.

3. ELECTRONIC/MECHANICAL GUIDE-IN SYSTEMS FOR AIRCRAFT ON THE AIRPORT SURFACE

   For aircraft forced to hold on the apron to wait for manual guidance to the gate, electronic or mechanical guide-in systems can be employed. Aircraft parking can, therefore, be achieved with minimal aid of ground personnel and with minimal delay. The technology exists for such nonmanual guide-in systems.

4. EXPANDED AUXILIARY POWER UNIT (APU) CAPABILITY ON GROUND

On the ground, expanded APU capability could meet the requirements for powered landing gear wheels, eliminating the need for all ground operation of the main engines. This application would save fuel, reduce airport pollution, reduce airport noise, and increase usage of cheaper, nose-in type gates.

5. EXPANDED APU CAPABILITY IN FLIGHT

In a typical application, the auxiliary power unit supplies compressed air for cabin airconditioning and startup of the main engines. It also provides shaft power for a hydraulic pump as an alternator for use in ground checkout. For the majority of flight time, the APU is essentially dead weight. By reconfiguring the APU to handle all of the aircraft secondary power needs in flight, its role is enlarged and conserves fuel by constraining the high-thrust main engines to prime propulsion.

6. MIXED - MODE TRAVEL

Transportation fuel use could be reduced by shifting traffic from airplanes to more fuel-efficient modes. The possibilities for implementing such a shift are greatest in the short haul markets. Short stages are particularly energy intensive. If the frequency of short haul trips were reduced, airplanes would increase their energy efficiency. A viable alternative would be the Metroliner. The Metroliner offers better times (better than any alternative transportation mode) for trips up to 140 miles.

7. ENERGY SAVING AIRPORT CONSTRUCTION PRACTICES

Projects which are deemed to have significant fuel or energy savings potential include:

- Fluorescent runway and taxiway lights.
- Concrete pavements constructed of a combination of cement and fly ash.
- Asphalt pavements wherein sulfur and carbon black are combined with asphalt.
- Water base paint as a substitute for paints with a petroleum base.

8. RECYCLE PAVEMENTS IN AIRPORT CONSTRUCTION

Whenever feasible, pavements could be recycled to eliminate the need to process and transport additional material to the airport construction site. Savings result from the reuse of old aggregate and asphalt.

9. DIGITAL AVIONICS

None of our present aircraft incorporate digital avionics on an extensive basis. Most systems are analog in nature and a current jet transport incorporates 12 or more systems that serve as computers. Fundamentally, digital systems not only improve precision, capacity, and reliability, but for a given function, they cost about half as much to construct and deliver. Their maintenance cost can be as little as a quarter to a half that of a nonintegrated analog system. From a fuel conservation standpoint, their primary benefit appears to be possible weight reduction.

10. GENERAL DRAG REDUCTION

- o Fillet/Fairing Modifications.
- o Improved Seals.
- o Slat/Flap/Spoiler Retraction Clean-Up.
- o Door/Control Surface Rigging.

11. LIQUID METHANE ENGINES

Liquid methane has a heating value per pound that is 20 percent greater than that of kerosene, but its density is only half as great. The methane is in the form of a liquid at -161°C at atmospheric pressure. Its cost is in the same general range of kerosene fuels. Liquid methane is a cryogenic with all of the storage and handling problems associated with very low temperature fuels. Although its higher heating value somewhat diminishes the total fuel requirement to accomplish a given pay-load-range task, the improvement is modest, more fuel tankage is required because of its low density, and the cryogenic nature of the fuel requires special tank design and special handling facilities.

12. LIQUID HYDROGEN ENGINES

The substitution of liquid hydrogen for petroleum-based jet fuel, while not leading to a conservation of total energy, would lead to a reduction in energy consumption of oil. The hydrogen would either

be obtained from coal or from water. The period 1990-2000 is considered the earliest that liquid hydrogen technology would be applied. Liquid hydrogen is attractive because of its cleanliness (byproducts are water and small quantities of oxides of nitrogen) and its high heat value per unit of weight (2.8 times that of kerosene for the same weight fuel). Its disadvantage of low density means that 3.8 times the storage volume is required for hydrogen. For the same payload, aircraft using hydrogen as a fuel would be about one-third lighter on takeoff, but substantially larger. An unresolved problem is the crash-worthiness of a hydrogen-fueled aircraft. If the -253°C liquified gas did not ignite, it could flash-freeze passengers if it got into the aircraft cabin. Because of the shape required of the pressure vessels holding the liquid hydrogen, it is not considered feasible to install them inside the wings. Subsonic designs variously call for hydrogen tanks fore and aft of the passenger compartment, above or below the passengers, and in the form of double-bubble fuselage or in large external tanks mounted on the wings. The latter has high drag, but may be preferable in order to separate the passengers from the fuel and to facilitate refueling. Although the aerodynamic drag and additional weight of the larger fuselage decrease the efficiency of the hydrogen airplane designs, its lower takeoff gross weight requires, on balance, a lower energy per mile than the kerosene-fueled airplane. The long range flights, the lower BTU requirements is significant. There has been much talk about the "hydrogen economy" and its application to aircraft with the use of liquid hydrogen economy is not a fundamental source of energy; it is only a carrier. The real source of energy would be the nuclear, solar, and geothermal powerplants that generate electricity from which the hydrogen is produced, probably by electrolysis. Liquid hydrogen is a superior propulsion system in the hypersonic regime due to its superior supersonic burning and airframe cooling capacity.

13. NUCLEAR ENGINES

The use of nuclear power as a fuel source for aircraft requires very large aircraft for feasibility. Nuclear airplanes realize a reasonable payload/gross weight ratio only with gross weight over one million pounds. Such an aircraft would, therefore, weigh about 50 percent more than an B-747 but would have the potential for continuous flight for up to 10,000 hours. The advanced turbofan engines can be powered either by kerosene fuel in a conventional manner or by the nuclear propulsion system. Takeoff, initial climb, and landing would be accomplished with kerosene-type fuel. This allows the nuclear powerplant to be designed to the lower power requirements of cruising flight. It also allows the nuclear reactor to be shut down during takeoff and landing. The probable location

of the reactor would be in the center of the fuselage. The reactor and its cooling fluid (either helium or liquid potassium) would be radioactively shielded and contained within a crashproof container. The heat generated is passed via heat exchange to a second fluid system (also helium) that is used to transport the energy out to the engines. This second fluid system has self-contained turbomachinery units that absorb the power transported by the helium working fluid. The main engine fans are shaft-driven from the individual helium-powered turbomachinery units. The aircraft engines would likely be located in the wing root, allowing short duct lengths from the reactor to the engines. The economics of nuclear airplanes differ somewhat from those of conventional airplanes because the fuel costs are substantially reduced. Therefore, a nuclear airplane can involve a higher initial cost than a conventional aircraft and still be economically competitive. Propulsion systems for nuclear engines are adequate primarily for subsonic operation.

14. RUNWAY EXTENSIONS TO ACCOMMODATE WIDE-BODY AIRCRAFT

Wide-body aircraft can be used in a fuel-efficient manner when two or more flights of a smaller aircraft, such as a B-727, can be replaced by one flight of a wide-body aircraft such as a B-747. In order for these possible fuel savings to be fully realized, more runways of a sufficient length to handle wide-body aircraft are needed. The B-747 runway length requirement is approximately 11,000 feet. The runway length requirement is trip length dependent, as well as aircraft size dependent. However, since fuel savings from changing to wide-bodies will tend to be more significant for longer stages, the need for more longer runways is valid.

An additional benefit of shifts toward wide-body aircraft is a reduction in delay due to fewer flights required to carry the same number of passengers. With several airports using quota systems on inbound traffic, the only manner by which greater demand can be handled is through wide-body aircraft replacing narrow-body.

15. VARIABLE CYCLE ENGINE

The future of supersonic transportation is largely dependent upon engine technology. The next generation SST will probably rely upon a variable cycle engine in order to improve performance and lower fuel consumption. Such an engine could operate as a high-bypass turbofan or as a turbojet. That is, it allows the operation of an efficient subsonic engine cycle during subsonic flight speeds and of an efficient supersonic engine cycle at supersonic flight speeds.

In one possible configuration, the change in cycle is provided by a valving arrangement whereby a simple twist of a portion of the

engine ducting about the engine axis provides a change in air-flow paths within the engine changing the engine characteristics from turbofan to turbojet.

Because the airframe and engine are better matched at both subsonic and supersonic speeds, the fuel burned per passenger-mile is improved over the entire flight. Since the efficiency improvement is somewhat greater at subsonic speeds, a second-generation SST might offer more efficient subsonic cruise operation and the potential for substantial total range improvement.

16. PROPFAN AIRCRAFT

Several advanced propfan aircraft designs have been considered since the OPEC embargo due to the fact that the propfan aircraft is relatively more fuel-efficient than turbofans or turbojets. The CL1320-15 design by Lockheed-California is typical of these advanced propfans. It is a 200 passenger, 1,500 nautical mile, MGTOW of 108.7 tons which flies at 0.8M using four Pratt & Whitney STS476 Rematch Turboshift Engines with 12.6 feet Hamilton standard propellers. It would cost slightly more than a comparable turbofan, but would have direct operating costs 9 percent lower due to less fuel burn. Cabin noise would be higher for the propfan than for the turbofan.

17. OBLIQUE-WING TRANSONIC AIRPLANE

NASA's Ames Research Center has been investigating oblique-wing concept applications for a variety of aircraft speeds (.8M to 2.3M), specifically for transonic transports. The concept involves a subsonic straight wing mounted atop a fuselage and pivoted so that it can be positioned at 90 degrees to the fuselage for takeoffs and landings and at various oblique angles for high speed flight (cruise position about 55 degrees). In the cruise position, the wing avoids the shock wave interference effects that occur with bilaterally symmetric wings.

This type of aircraft would be optimized to fly at the threshold Mach number, that is, the fastest Mach number at which supersonic flight is possible without sonic boom. The precise value of the threshold Mach number is a function of airplane flight altitude and the meterorological conditions. Over the United States, it typically varies from about Mach 1.00 to Mach 1.35. This variability of Mach number, together with the possibility to go even faster over water, justifies the variable sweep for this type of aircraft. The single-pivot variable-sweep wing leads to low drag at many flight conditions, is structurally feasible, and appears to be considerably more promising than the more conventional dual-pivot variable-sweep wing.

18. SECOND-GENERATION SST

The reason for the supersonic transport is that travelers usually have shown preference for the quickest point-to-point service. Supersonic transports, the Concorde and TVU-144, already exist and the shape of a future, second-generation SST will follow from evolutionary modifications to these aircraft.

For lower fuel consumption, it will be necessary to increase the supersonic aerodynamic efficiency of the airplane by incorporating design features that reduce wave drag. If the transonic drag can be reduced at the same time, it will be possible to design the SST with an engine that is no bigger than that required to match the airplane drag at high altitude, high Mach number cruise, and which also does not need the addition of the fuel-inefficient afterburner.

To eliminate the afterburner, it will be necessary to design the airframe so that extra afterburning thrust is not needed anywhere in the flight envelope. Since the transonic portion of climb to cruise altitude is one of the most critical portions of a supersonic aircraft's mission, particular care will have to be given to develop an airframe shape that has low transonic as well as supersonic drag.

To lower vave drag at all Mach numbers requires complete integration of airplane fuselage and wing structure. In addition to an integrated wing-fuselage, the designer will have to rely even more on the standard aerodynamic approaches to reduce drag. These include approaches such as area ruling, camber and twist, propulsion system placement, variable camber, and negative trim drag.

Because of sonic boom, it has been found undesirable to operate aircraft at supersonic speeds over populated areas. Since most long range routes include flight over land masses, an advanced SST must be highly efficient in its subsonic flight capability. The main efficiency problem of the supersonic airplane in subsonic flight is the engine specific fuel consumption. The poor subsonic engine efficiency has prompted research into multicycle or variable cycle engines.

19. LAMINAR FLOW CONTROL

A large portion of the total drag of subsonic airplanes at cruising speeds is due to skin friction drag, or the drag to shearing forces imposed on surfaces of the aircraft exposed to high-speed flow. By maintaining the maximum amount of laminar flow during

high-speed flight, when the boundary layer tends to become turbulent, significant overall drag reductions can be achieved and cruising efficiency enhanced. Low-speed, long-range aircraft would benefit most, since it is easier to maintain laminar flow on unswept surfaces and since drag reduction is more important for long-range aircraft. Practical problems such as high weight and manufacturing costs coupled with an anticipated high cost of maintenance has in the past prevented the use of laminar flow control.

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